Corrosion

Official Publication

NATIONAL ASSOCIATION OF CORROSION ENGINEERS
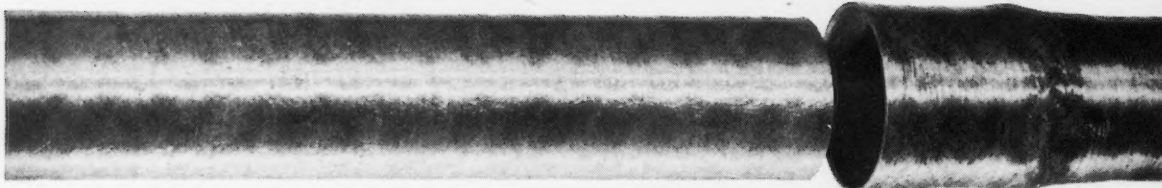
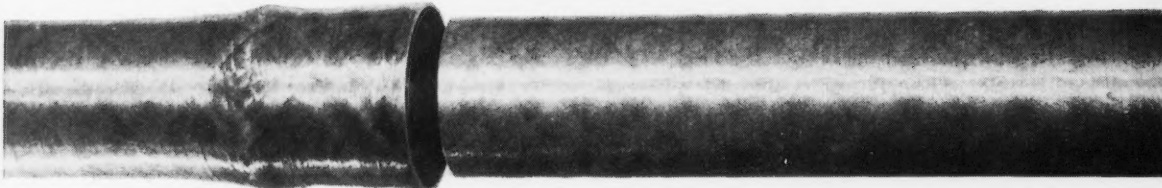# CONTENTS

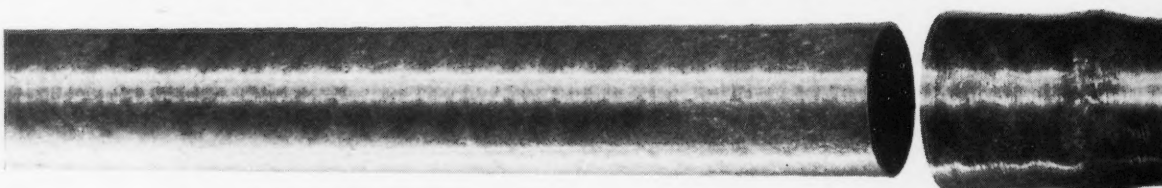## TECHNICAL SECTION

Technical Articles Scheduled for Publication in June

CONTENTS

x

Nace News

Report on the 14th Annual Conference

General News

Technical Topics

THIS MONTH'S COVER—This view of the exhibition floor at San Francisco's civic auditorium indicates the variety of products on exhibit and to some extent the degree of interest in the show by conference registrants. Twenty of the 83 companies exhibiting either were West Coast firms or branches of firms domiciled elsewhere.

☆

NACE Corporate Members and Representatives

Administracion Nacional de Combustibles Alcohol y Portland, Ing. Ezequiel Perez Prins
Alabama Gas Corporation T. G. Humphreys, Jr.
Alco Products, Incorporated W. L. Clark
Allegheny Ludlum Steel Corp. William G. Renshaw
Allied Chemical & Dye Corp., Nitrogen Division H. C. Wintzer
Alloy Steel Products Co. R. M. Davis
Aluminium Laboratories, Ltd. H. P. Godard
Aluminum Company of America Ellis D. Verink, Jr.
Amercoat Corp. C. G. Munger
American Brass Co., The John R. Freeman, Jr.
American Chemical Paint Co. Alfred Douty
American Mollerizing Corp. H. E. Linden
American Smelting Refg. Co., Federated Metals Div. R. D. Taylor
American Telephone & Telegraph Co. A. F. Minor
American Tobacco Co., The A. R. Anderson
American Zinc, Lead & Smelting Co. Robert Ammon
Anderson-Prichard Oil Corp. Clyve C. Allen
Apex Smelting Co. A. J. Peterson
Aquaness Dept, Atlas Powder Co. Fritz E. Fuchs
Aquatrol, Inc. M. C. Forbes
Arabian American Oil Co. William F. Gross
Arizona Public Service Co. Frank Buck
Arkansas Fuel Oil Corp. L. F. Babcock
Arkansas Louisiana Gas Co. W. A. Broome
Armco Steel Corp. Arba Thomas
Armour Chemical Division, Armour & Co. J. E. Maloney
Atchison, Topeka & Santa Fe Railway Co., The E. R. Fields
Atlantic Pipe Line Co. (Penna.) Product Pipe Line Dept. Robert H. Lynch
Atlantic Refining Co., Producing Div., The V. E. Stepp
Atlantic Refg. Co., Refining Div., The J. K. Deichler
Atlas Mineral Products Co., The Joseph A. Snook

Babcock & Wilcox Co., The F. Eberle
Baltimore Gas & Electric Co. T. J. Dwyer
Baltimore & Ohio RR Co., The Charles H. Chlad
Barrett Div., Allied Chem. & Dye Corp. P. B. Mayfield
Bart Manufacturing Corp. S. G. Bart
Bataafsche Petroleum Mij., N. V. de J. H. G. Post
Bechtel Corporation G. R. Grable
Bell Telephone Lab. Vernon B. Pike
Bennett & Wright Limited J. M. Greenhill
Bessemer & Lake Erie Railroad Co. R. D. Lake
Bethlehem Steel Co. Seymour Charles Frye
Betz Laboratories, Inc. John J. Maguire
Bird-Archer Co., The Charles W. Bird
Blaw Knox Co., Chemical Plants Div. John Kull
Blaw-Knox Company, National Alloy Steel Div. M. N. Ornitz
Brance-Krachy Co., Inc. Wayne E. Broyles
Bridgeport Brass Co. R. V. Hall
Briggs Bituminous Composition Co. J. D. Farber
Briner Paint Mfg. Co., Inc. Felix Kelinske
British American Oil Co., Ltd. L. P. Blaser
British Petroleum Co., Ltd. J. E. Anderson
Buckeye Pipe Line Co. G. E. Baque
Bute Co., James Earl A. Benus
Byers Co., A. M. R. J. Briemont

California Research Corporation F. W. Schremp
Calumet & Hecla, Inc., Wolverine Tube Div. John M. Keyes
Cameron Iron Works, Inc. Rudy Zorn
Canadian Protective Coating Ltd. F. W. Hewes
Canadian Vickers Limited P. W. Gooch
Canadian Western Natural Gas Co., Ltd. B. W. Snyder
Carter Oil Co., The A. C. Broyles
Cathodic Protection Service E. P. Doremus
Celicote Co., Inc., The W. A. Severance
Celanese Corp. of America J. H. Baker
Central Power & Light Co. William M. Mayer
Centre Belge D'Etude de la Corrosion Marcel Pourbaix
Chain Belt Co. of Milwaukee Egmont R. Helmer
Champion Paper & Fibre Co., The Peter A. Kimen
Champlin Oil & Refining Co. K. C. Crilley
Chanslor-Western Oil & Dev. Co., Chanslor-Canfield Midway Div. H. L. Briggs
Chicago Bridge & Iron Co. J. E. Boberg
Chicago, Milwaukee, St. Paul & Pacific Railroad Co. Howard H. Melzer
Cincinnati Gas & Electric Co., The Milton J. Pfeiffer
Cit-Con Oil Corp. Robert L. Hale, Jr.
Cities Service Gas Co. George C. Roth
Cities Service Pipe Line Co. Harry Nelson
Cities Service Refining Corp. L. D. Mann
City of Long Beach, Harbor Dept. E. L. Crampton
Clementina, Ltd. K. F. Keefe
Clentex, Inc. Frank E. Wilson
Coast Paint & Lacquer Co., Inc. R. M. Johnson
Colorado Interstate Gas Co. Preston Parks
Columbia Gas System Service Corp. J. E. Overbeck
Columbia-Southern Chemical Corp. G. Heinemann
Columbus & Southern Ohio Electric Co. N. R. Patton
Commercial Solvents Corporation Richard S. Ealy
Commonwealth Associates Inc. W. E. Bunting
Commonwealth Edison Co. Earle Wild
Consolidated Edison Co. of New York, Inc. L. B. Donovan
Consolidated Mining & Smelting Co. of Canada, Ltd. J. R. Wellington
Consumers Power Co. J. B. Simpson
Continental-Emsco Co. George W. Whitney
Continental Pipe Line Co. A. C. Wilkinson
Cook Paint & Varnish Co. Decker Freeman
Cooper Alloy Corp. Herbert J. Cooper
Corn Products Refining Co. R. E. Pierson
Corrosion Rectifying Co. Wayne A. Johnson
Cosden Petroleum Corp. R. W. Thompson
Coutaulds (Alabama) Inc. J. W. Rollins
Crane Co. Chester Anderson
Creole Petroleum Corp. G. A. McCammon
Crown Central Petroleum Corp. A. J. Morris
Crucible Steel Co. of America D. I. Dilworth, Jr.
Crutcher-Rolfs-Cummings, Inc. Jack Scott

Dallas Power & Light Co. Robert D. Elliott
Dampney Co., The J. Dwight Bird
Davison Chemical Co., Div. of W. R. Grace & Co., Curtis H. Elliott, Jr.
Day, S. D., Co. David W. Peake
The Dayton Power & Light Co., Corrosion Control Dept. Paul C. Hoy
Dearborn Chemical Co., R. F. Carr, Jr.

Debevoise Co., The Robert L. Debevoise
Delhi-Taylor Oil Corp. Harry F. Warnke
De Vilbiss Co., The D. J. Peeps
Devoe & Raynolds Co., Inc., Truscon Labs Div., R. E. Madison
Diamond Alkali Company S. W. McIlrath
Dorr-Oliver, Inc. Dwight Richards
Douglas Aircraft Co., Inc. F. T. Wood, Jr.
Dow Chemical Co., The H. A. Humble
Dowell Incorporated Guy F. Williams
E. I. du Pont de Nemours & Co., Inc. J. A. Collins
Duriron Co., Inc., The G. A. Baker
Duval Sulphur & Potash Co. J. W. Borskey, Jr.

East Bay Municipal Utility District Lee B. Hertzberg
Eastern States Petroleum & Chem. Corp. Jack Dalberg
Ebasco Services, Inc. H. W. Wahlquist
Electric Steel Foundry Co. Charles E. Haney
Electro Rust-Proofing Corp. Frank P. Macdonald
El Paso Natural Gas Co. L. G. Wahman
Esso Research & Engineering Co., Design Div., M. S. Northup
Ethyl Corp. H. S. Butler

Fabri-Valve Co. of America J. L. Williams
Fibreboard Paper Products Corp. Pabco Indus. Insulations Div. L. S. Parker
Frances Oil Co. Frances Olsan
Freeport Sulphur Co. Wm. L. Vorhies
Furane Plastics Inc. John Delmonte

F. W. Gartner Company F. W. Gartner, Jr.
Gates Engineering Co. A. J. Seller
General American Transportation Corp. Paul Talmey
General Chemical Div., Allied Chemical & Dye Corp. W. H. Burton
General Electric Co., Industrial Materials Div., G. V. Browning
General Petroleum Corp. Ralph M. Willits
Gibbs & Hill, Inc. E. H. Anson
Good-All Electric Mfg. Co. Troy R. Stilley
B. F. Goodrich Chemical Co. Jean F. Malone
Graver Tank & Mfg. Co., Inc. Phillip E. Rose
Great Lakes Pipe Line Co. C. C. Keane
Great Northern Railway Co. G. V. Guerin
Gulf Oil Corp. Walter F. Rogers
Gulf Oil Corp., Mfg. Div. D. L. Burns
Gulf Research & Development Co. L. W. Vollmer
Gulf States Utilities Co. W. W. Eckles
Gunnels Co., W. D. Wm. H. Stemler

Hackensack Water Co. A. Damiano
Hagan Chemicals & Controls, Inc. Threshold Treatment Div. John P. Kleber
Halliburton Oil Well Cementing Co. Warren H. Philipp
Harbison-Fischer Manufacturing Co. D. T. Harbison
Hercules Powder Co., Chemical Eng. Div. David J. Torrans
Hill, Hubbell & Company, Division of General Paint Corp. Milton M. Bowen
Holcombe Company, Inc., The Tom L. Holcombe
Holders Equipment Co. S. D. McMullen
Hooker Electrochemical Co. Walter A. Szymanski
Houston Contracting Co. R. P. Gregory
Houston Natural Gas Corp W. C. Dahlman
Houston Pipe Line Co. H. D. Carmouche

Huddleston Engineering Co. Wm. E. Huddleston
Humble Oil & Refining Co. H. D. Wilde
Humble Pipe Line Co. A. E. Pecore
Hydro-Electric Power Commission of Ontario, The D. G. Watt

Imperial Oil, Ltd., Pipe Line Division L. Garcia
Imperial Oil, Ltd., Prod. Dept., Western Div. J. W. Young
Imperial Pipe Line Co., Ltd., The E. W. Christian
Inland Steel Co., Res. & Dev. Dept. R. L. Harbaugh
International Harvester Co. Earl F. Moorman
International Minerals & Chemical I. M. LeBaron
International Nickel Co., Inc., The W. Z. Friend
International Nickel Co. of Canada, Ltd., The R. J. Law
International Paint Co., Inc. Albert R. Smiles
International Rectifier Corp. F. W. Parrish
Interprovincial Pipe Line Co. F. J. Stubbs
Iowa Public Service Co. Wm. J. Dougherty
Iranian Oil Refining Co., N. V., Technical Service Dept. A. K. J. Van Schravendijk

Johns-Manville Sales Corp. Clark A. Bailey
Jones-Blair Paint Co. L. R. Kyrias
Jones & Laughlin Steel Corp. H. T. Clark

Kaiser Steel Corporation John S. Klusman
Kansas-Nebraska Natural Gas Co., Inc. Leonard C. Hill
Kansas Power & Light Co., The W. J. White
M. W. Kellogg Co., The W. B. Hoyt
Kendall Co., The, Polyken Sales Division, Howard D. Sezool
Keystone Roofing Manufacturing Co. Stephen A. Feely
Keystone Shipping Co. S. F. Spencer
Knapp Mills, Incorporated Alfred P. Knapp
Koppers Co., Inc., Tar Prod. Div. W. F. Fair, Jr.

L. O. F. Glass Fibers Co. M. W. Gregory
Laclede Gas Co. Delmar Hasenritter
Lester Equip. Manuf. Co., Inc. Don P. Wilson
Lever Brothers Co. Franklin McDermott
Lion Oil Co. J. B. Rogerson
Lone Star Gas Co. J. L. Foster
Long Island Lighting Co. William Welch, Jr.
Louisiana Power & Light Co. W. T. Hess
Lubrizol Corp., The Willis G. Craig

Magnolia Petroleum Co. J. D. Humble
Magnolia Pipe Line Co. James R. Ashley
Mallinckrodt Chemical Works C. A. Coberly
F. H. Maloney Co. James H. McBrien
Manning, Maxwell & Moore, Inc. Robert F. Ehrsam
Mavor - Kelly Company Thos. F. P. Kelly
Metal Goods Corp. Charles G. Gribble, Jr.
Metallizing Engineering Co. R. J. McWaters
Metropolitan Water District of So. Calif. R. B. Diemer
Michigan Consolidated Gas Co. Karl E. Schmidt
Michigan-Wisconsin Pipe Line Co. J. L. Thompson
Mid-Continent Pipe Line Co. F. E. Pyeatt, Jr.
Mid-Valley Pipeline Co. F. H. Deal
Midwestern Pipe Line Products Co. John R. Wilson
Minnesota Mining & Mfg. Co. F. J. Wehmer

NACE Corporate Members and Representatives

Mississippi River Fuel Corp.
G. B. Lowther
Mississippi Valley Gas Co.
J. H. Lambdin
Monsanto Chemical Co.
F. L. Whitney, Jr.
Montana Power Co.
Carl R. Davis
Mountain Fuel Supply Co.
Harry R. Brough
Mutual Chemical Div.,
Allied Chem. & Dye Corp.
George E. Best

Napko Corp.
Joseph E. Rench
National Aluminate Corp.
J. W. Ryznar
National Lead Co.
Roy Dahlstrom
National Supply Co., The,
Spang-Chalfant Division
Lawrence E. Trishman
National Tank Co.
Clarence O. Glasgow
Natural Gas Pipeline Co. of America
A. F. Schmierer
New Jersey Zinc Co. of Pa., The,
Research Dept.
E. A. Anderson
New Orleans Public Service, Inc.
Lionel J. Cucullu
Nicolet Industries, Inc.
Ladd L. Wilson
Nooter Corp.
P. H. Smith
Norfolk & Western Railway Co.
C. L. Crockett
Northern Illinois Gas Co.
M. G. Markle
Northwestern Utilities, Ltd.,
M. E. Stewart

Oakite Products, Inc.
Robert F. Ayres
Ohio Oil Co., The
Ralph M. Slough
Oil Well Supply Co.
F. L. Current
Oklahoma Natural Gas Co.
P. K. Wallace
Olin Gas Transmission Corp.
O. C. Roddey
Omaha & Council Bluffs Electrolysis
Committee
R. A. Pesek
Otis Pressure Control, Inc.
W. M. Kelly
Owens-Corning Fiberglas Corp.
E. J. Pennell

Pacific Gas & Elec. Co.
Roy O. Dean
Pacific Lighting Gas Supply Co.
N. K. Senatoroff
Pacific Northwest Pipeline Corp.
William C. Brady
Page-Hersey Tubes, Ltd.
John D. Breithaupt
Pan American Petroleum Corp.
Joseph B. Clark
Panhandle-Eastern Pipe Line Co.
M. K. Hager
Parker Rust Proof Co.
E. W. Richards
Pennsalt Chemicals Corp.
R. R. Pierce
The Pennsylvania Railroad Co.
M. A. Pinney
Peoples Gas Light & Coke Co., The
J. L. Adkins
Perrault Equipment Co.
V. V. Malcom
Petrolite Corp.
G. J. Samuelson
Philadelphia Electric Co.
E. S. Halfmann
Philip Carey Manufacturing Co., The
W. T. Ferrell
Phillips Petroleum Co.
Frederick A. Prange
Pipe Line Service Corp.
F. C. Yeazel

Pipe Linings, Inc.
Robert L. Hansen
Pittsburgh Coke & Chemical Co.
A. E. Gray
Pittsburgh Plate Glass Co.
Firmin A. Hickey
Plantation Pipe Line Co.
W. G. Horstman
Plastic Applicators, Inc.
H. M. Kellogg
Plastic Engineering & Sales Corp.
R. B. Bender
Plicoflex, Inc.
B. E. Black
Portland Pipe Line Corporation
Carlton L. Goodwin
Potash Company of America
John S. Alexander
Premier Oil Refining Co. of Texas
David D. Pickrell
H. C. Price Co.
R. P. White
Procter & Gamble Co., Engr. Div., The
George F. Lockeman
Production Profits, Inc.
H. L. Bilhartz
Products Research Service, Inc.
Philip B. Wogan
Public Service Electric & Gas Co.
Donald C. Luce
Pure Transportation Co.
D. C. Glass

Raytherm Corporation
F. Raymond Young
Reilly Tar & Chemical Corp.
J. H. Barnett, Jr.
Remco Pipeline Equipment & Supplies
Bo Bardsley
Republic Steel Corp.
Giles Locke
Reynolds Metals Company
Robert S. Dalrymple
Cyrus Wm. Rice & Co.
James K. Rice
Richfield Oil Corp.
D. F. Purdy
Robinson, E. W. Supply Co.
T. S. Blanton
Rochester Gas & Electric Corp.
Edward J. Nelson
Rockwell Manufacturing Co.
Jack W. Harris
Rockwell Mfg. Co., Nordstrom Valve Div.
J. B. Dotson
Rosson-Richards Co.
S. L. Richards, Jr.
Russell, G. L., & Company Ltd.
Gordon I. Russell
Rust Proofing, Inc.
Harold B. Newsom

St. Joseph Lead Co.
Dwight Marshall
St. Louis Metallizing Co.
Walter B. Meyer
St. Louis-San Francisco Railway Co.
B. H. Crosland
Salt Lake Pipe Line Co.
L. G. Haskell
San Diego Gas & Electric Co.
Donald P. Armbruster
San Francisco Water Dept.
James H. Turner
Sargent & Lundy
Ludwig Skog, Jr.
Sensitive Research Instrument Corp.
H. Russell Brownell
Service Pipe Line Co.
J. R. Polston
Shamrock Oil & Gas Corp., The
Dan P. Long
Shell Chemical Corp.
A. L. Petersen
Shell Development Co.
R. S. Treseder
Shell Oil Co., Inc.
J. G. Wilson
Shell Pipe Line Corp.
O. W. Heyden
Shippers' Car Line Corp.
Ernest H. Colby
Signal Oil & Gas Co.
E. O. Kartinen

Sinclair Oil & Gas Co.
E. H. Counts
Sinclair Pipe Line Co.
Glenn L. Ladd
Sinclair Research Laboratories, Inc.
F. M. Watkins
Sline Industrial Painters
Louis L. Sline
A. O. Smith Corp.
L. C. Wasson
Socony Mobil Oil Co. Inc.,
Central Pipe Lines Div.
Gerald J. Paisley
Socony Mobil Oil Co. Inc.,
Eastern P. L. Div.
S. Kleinheksel
Socony Paint Products Co.
Paul L. Lotz
Sohio Petroleum Co.
S. B. Lisle
Sohio Pipe Line Co.
A. A. Dorffi
South African Bureau of Standards
Clemens Crispus Van Der Merwe
Southeastern Pipe Line Co.
B. W. Winters
Southern Bell Telephone & Telegraph Co.
T. J. Cook
Southern California Gas Co.
J. S. Dorsey
Southern Counties Gas Co. of Calif.
W. C. Mosteller
Southern Minerals Corp.
F. P. Peterson, Jr.
Southern Natural Gas Company
O. W. Clark
Southern Pacific Company
W. M. Jaekle
Southern Union Gas Co.
N. P. Chesnutt
Southland Paper Mills, Inc.
A. E. Drew
Southwest Natural Gas Co.
F. A. Merfeld
Southwestern Gas & Electric Co.
Frank M. Wilkes
Southwestern Plastic Pipe Co.
Ray S. Perkins
Southwestern Public Service Co.
H. O. Hodson
Spencer Chemical Company
Ralph D. Miller
Standard Oil Co. of Calif.
D. Rozer Loper
Standard Oil Co. (Ind.),
Pro. Pipe Line Dept.
V. M. Kalhauge
Standard Pipeprotection, Inc.
Hugh W. Baird
Standard Railway Equipment Mfg. Co.
J. S. Swann
Stauffer Chemical Co.
J. B. Ceccon
D. E. Stearns Co., The
D. E. Stearns
S. T. E. C. T. A.
Georges Poirier
The Hayne Stokes Co.
Hayne Stokes, Jr.
Sun Oil Co. Production Laboratory
William F. Oxford
Sun Pipe Line Co.
W. H. Stewart
Sunray Oil Corp.
R. H. Poetker
Superior Iron Wks. & Sply. Co., Inc.
V. J. Martzell
Superior Oil Company, The
William H. Edwards

Tennessee Gas Transmission Co.
J. L. Parrish, Jr.
Texaco-Cities Service Pipe Line Co.
B. W. Nedbalek
Texas Company, The
W. S. Quimby
Texas Eastern Transmission Corp.
Pat H. Miller
Texas Electric Service Co.
C. W. Geue
Texas Gas Transmission Corp.
Fred D. Stull
Texas Gulf Sulphur Co.
C. O. Stephens

Texas Pipe Line Co., The
Paul T. Miller
Texsteam Corporation
L. V. Musgrove
Tex-Tube, Inc.
R. W. Kearney
Thornhill-Craver Co.
C. R. Horn
Tidewater Oil Co.
A. M. Mouser
Tinker & Rasor
Leo H. Tinker
Trans-Arabian Pipe Line Co.
P. P. Nibley
Transcontinental Gas Pipe Line Corp.
S. J. Bellassai
Trans Mountain Oil Pipe Line Co.
David M. Allan
Trans-Northern Pipe Line Co.
L. R. Dickinson
Tresco, Inc.
D. L. Korn
Triangle Conduit & Cable Co., Inc.
Clyde V. McKay
Trunkline Gas Co.
A. T. Surber, Jr.
Tube-Kote, Inc.
E. G. Holm
Tube Turns Plastics, Inc.
George H. Hunt
Tuscarora Pipe Line Company, Ltd.
John W. de Grott

Union Carbide Corp.
George A. Sands
Union Electric Co.
George P. Gamble
Union Gas Company of Canada, Ltd.
Ralph E. Kuster
Union Oil Co. of Calif., Research Center
J. E. Sherborne
Union Pacific Railroad Co.
Lee S. Osborne
Union Producing Co.
E. L. Rawlins
United Gas Corp.
C. L. Morgan
United Gas Pipe Line Co.
M. V. Cousins
United States Pipe & Foundry Co.
A. E. Schuh
U. S. Steel Co., National Tube Division
V. V. Kendall
United States Steel Corp., Applied
Research Laboratory
C. P. Larrabee
Universal Control Corp.
Charles D. Peterson
Universal Oil Products Co.
Eugene M. Matson

Vapor Honing Co., Inc.
Jack Eggleston
Vapor Recovery Systems Co.
Frank V. Long, Sr.
Visco Products Co., Inc.
D. M. Jacks

Weirton Steel Co.
E. O. Burgham
Western Kentucky Gas Co.
J. L. Bugg
Western Natural Gas Co.
Paul C. Wright, Jr.
Wheeling Steel Corporation
Henry A. Stobbs
Williams Brothers Co.
C. M. Collins
T. D. Williamson, Inc.
T. D. Williamson, Jr.
Wisconsin Protective Coating Co.
Francis J. Ploederl
Worthington Corp.
W. M. Spear
Wright Chemical Corp.
Paul G. Bird
Wyandotte Chem. Corp.
L. W. Gleekman

Youngstown Sheet & Tube Co., The
Karl L. Fetters

Changes—NACE Regional and Sectional Officers' Directory

● **Kanawha Valley Section**

George C. Cox, Chairman; 3711 Washington Avenue, S. E., Charleston 4, West Va.

Conrad L. Wiegers, Vice-Chairman; Allied Service, Inc., 160 Spring Street, Station A, Charleston, West Va.

Kenneth R. Gosnell, Secretary; Dev. Dept., Union Carbide Chemicals Company, South Charleston, West Va.

● **Carolinas Section**

Ray Penrose, Vice-Chairman; Aluminum Company of America, 1000 Wachovia Bank Building, Charlotte, N. C.

Robert H. Gardner, Secretary-Treasurer; Koppers Company, Inc., Tar Products Div. P. O. Box 1688, Charlotte, N. C.

● **Montreal Section**

H. H. Yates, Chairman; Redpath Library, McGill University, 3459 McTavish Street, Montreal, Quebec, Canada

M. D. Phillips, Vice Chairman; McColl-Frontenac Oil Company Ltd., 10200 Notre Dame Street, East; Montreal, Quebec, Canada

D. B. Bird, Sec.-Treas.; Aluminum Company of Canada, Ltd., 1700 Sun Life Building, Montreal, Quebec, Canada

● **Central Arizona Section**

Harold B. Newsom, Chairman; 25 South Lazona Drive, Mesa, Arizona

William B. Lewellen, Vice-Chairman; Deer-O-Paints and Chemicals Ltd., P. O. Box 990, Phoenix, Arizona

Lee Homrighausen, Secretary; Arizona Public Service Co., P. O. Box 2591, Phoenix, Arizona

TITANIUM–available <u>now</u> for long service
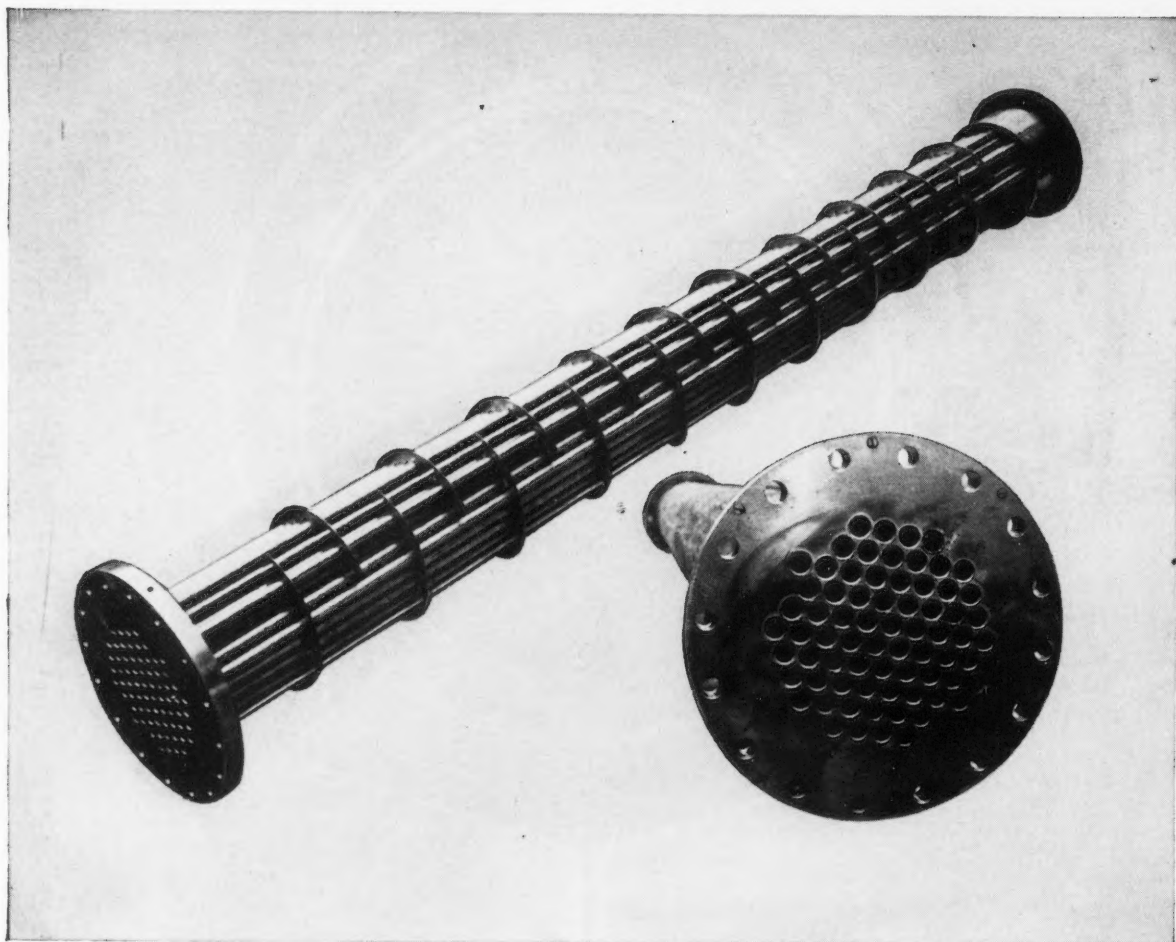
• *The life of this titanium 70-tube condenser assembly, now handling 60% nitric acid at 195° C. and 180 psi, is estimated to exceed 10 years.*

Titanium condenser tubes expected to outlast stainless 30 to 1 handling nitric acid

Corrosive vapors of 60% nitric acid gnawed through an average of three stainless-steel tube bundles a year in a chemical firm's condenser. Maintenance and replacement costs were running as high as $18,000 a year. Then titanium tubes were installed. Based on a service life of 10 years, titanium will save at least $162,000 in maintenance and replacement costs.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

(h) To invite a wide diversity of memberships, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers and elected directors are nominated by a nominating committee in accordance with the articles of organization. Election is by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 1061 M & M Building, No. 1 Main Street, Houston 2, Texas.

OFFICERS, 1958-59

President...............................L. L. WHITENECK

Vice-President...........................HUGH P. GODARD

Treasurer..................................A. L. STEGNER

Executive Secretary..........................T. J. HULL

1061 M & M Bldg., Houston 2, Texas

Corrosion and the Destination of Corrosion Products In A High Pressure Power Plant*

By ROSS C. TUCKER

Introduction

THIS DISCUSSION reviews the methods used to reduce corrosion, and considers the formation and transportation of corrosion products within the cycle of a high pressure steam generating plant.

Experiences with 16 high pressure units within the Niagara Mohawk Power system are related in detail. Four of these units are at the Oswego Steam Station (Figure 1). The most recent addition at that station consists of a radiant type boiler with a steam capacity of 655,000 lb/hr, superheat outlet pressure of 1492 psi, final steam and reheat temperature of 1000 F, and feedwater temperature of 456 F. A 3600 RPM, 23 stage tandem compound reverse flow high pressure, double flow low pressure turbine, drives a 100,000 KVA, 13,000 V generator sealed in an atmosphere of hydrogen.

It is generally considered that most of the corrosion products found in high pressure boiler deposits originate within the steam and feedwater portion of the cycle. Many boiler tube failures are due to accumulations of this sludge, composed predominately of black magnetic iron oxide and metallic copper. The failures are frequently located in sections that under full load operation have excellent circulation and apparently none of the factors that contribute to serious corrosion. However, during low load or shutdown periods, these locations, which are usually in tubes approaching the horizontal position, favor the accumulation of sludge normally held in suspension or retained in headers and drums. The oxides settle on the tube surface, become baked into such a dense mass that upon restoring the unit to service, normal circulation is not sufficient to remove the deposit. Thus a corrosion cell with a relatively small anodic area is created. Then boiler water salts begin to concentrate, the rate of corrosion increases, tube thinning and

About the Author

ROSS C. TUCKER is laboratory supervisor at the Oswego Steam Station, Niagara Mohawk Power Corporation, Oswego, New York. He has an AB degree from Syracuse University and is a member of the National Association of Corrosion Engineers and the American Chemical Society.

metal overheating become companion events, and finally the tube fails.

Water Conditioning

A statement concerning the water conditioning at this station is requisite to a consideration of the corrosion within the feedwater-boiler-steam cycle. The unit is a closed cycle with a make-up requirement of about 2500 lb/hr of condensate. This is prepared by subjecting Lake Ontario water to sodium and hydrogen zeolite exchange, aeration, deaeration, and finally, evaporation. The make-up is admitted at the main condenser, where vacuum deaeration reduces the dissolved gases to a minimum. Chemical control of the boiler water is accomplished by the injection of potassium hydroxide and potassium phosphate. In the typical boiler water analysis shown (Table 1), the pH is adjusted to a value of 10.5 to 11.0, a range in which the oxide film protecting the tube surfaces is reported to be most stable. The "A" and "B" readings are the number of ml of thirtieth normal HCl required by a 100 ml sample taken

Abstract

Methods used to reduce corrosion in a high pressure steam generating plant are reviewed. Factors involved in the formation, transportation and deposition of corrosion products within the plant's cycle are discussed in detail. Attention is given in the discussion to such matters as water conditioning, feedwater and steam concentrations, corrosion of steam lines, turbine blade deposits, the collecting of dissolved gases in condensers, and dissolved oxygen scavengers. Under certain abnormal conditions (erection of plant, low load operation, and shut-down periods), the chemist may have relatively little control over the corrosion occurring.

8.2.2

to the phenolphthalein endpoint, first as sampled, then after the addition of BaCl₂ to precipitate the carbonate and phosphate. By such a titration one obtains for the "A" reading all the free alkalinity, nearly all of the hydrolytic alkalinity of the silicate, and one-third of the equivalents of the phosphates present. The "B" reading represents only the free hydroxide.

Boiler phosphate concentration is maintained at 2 to 3 ppm as an insurance against the possibility of scale formation from hardness entering the cycle through condenser tube leakage. This same leakage is responsible for the presence of chlorides, sulfates, and silica. Electrolytic conductivity confirms the results of chemical analysis with respect to total ionized solids. By continuously recording the conductivity, the admission of soluble contaminants, or the loss of boiler water concentrations through blowdown or tube leakage can be detected immediately and corrective treatment applied before serious damage occurs.

Morpholine is fed into the main condenser hotwell for the purpose of pH control of the feedwater and steam. It was selected for this use from a choice of several amines because it: (1) adds no total solids to the boiler, (2) apparently has no destructive effect on copper alloy heat exchange tubes, (3) is relatively stable up to boiler pressures of 2500 psi and steam temperatures up to 1200 F,[1] and (4) provides an alkaline environment not only in the feedwater
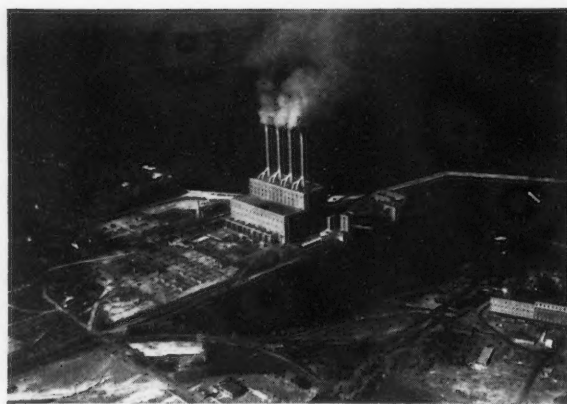
Figure 1—Aerial photograph of Niagara Mohawk Power Corporation's Oswego (New York) Steam Station.
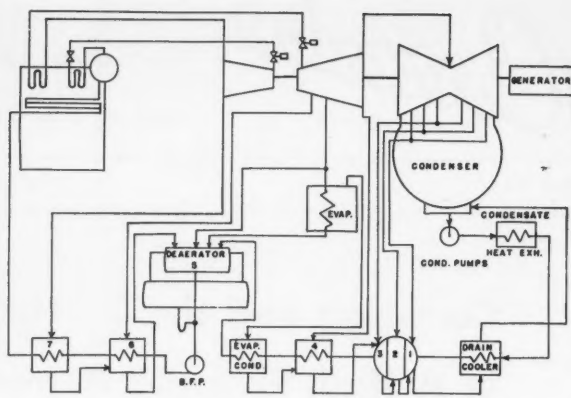
Figure 2—Flow diagram of Unit No. 4 cycle.

TABLE 1—Typical Boiler Water Analysis

ITEM	Value
"A" Reading	2.1 ml
"B" Reading	2.0 ml
Chloride (Cl)	1.9 ppm
Phosphate (PO_4)	2.3 ppm
Silica (SiO_2)	0.8 ppm
Sulfate (SO_4)	2.1 ppm
Total dissolved Solids	57 ppm
Conductivity	165 mmho
pH Value	10.8

TABLE 2—Chemical Concentrations at Full Load

LOCATION	CHEMICAL CONCENTRATION AND pH			
	Morpholine (ppm)	Ammonia (ppm)	Oxygen (ppm)	pH Value
Hotwell Pump Discharge	0.39	0.17	0.018	9.12
Inlet No. 1 Heater	0.40	0.13	0.015	9.10
Boiler Feed Pump Suction	0.30	0.20	0.003	9.12
Economizer Inlet	0.39	0.07	0.002	9.12
Saturated Steam	0.50	0.13	....	9.15
Superheated Steam	0.30	0.10	....	9.12
Reheater Inlet	0.39	0.10	....	9.12
Reheater Outlet	0.44	0.22	....	9.12

portion of the cycle, but also in the steam lines, turbine and condenser. This last-mentioned important property is due to the steam-water ratio of morpholine which is about 1.3 at the boiler temperature and pressure under which the unit operates. To obtain the desired pH value of 9 in the steam through a concentration of 4 ppm of morpholine, the boiler water concentration would be about 3 ppm.[2]

Feedwater and Steam Concentrations

Figure 2 is a flow diagram of the Unit No. 4 cycle. From this cycle samples can be obtained from the hotwell pump discharge, the inlet to No. 1 heater, the boiler feed pump suction, the economizer inlet header, saturated steam, superheated steam, and the reheat inlet and outlet. The results of analyses reported in Table 2 represent concentrations found at these sampling points, and are indicative of conditions under full unit load operation.

The Boiler

The boiler is the preferable starting point in the cycle to review conditions for the formation and transportation of corrosion products. An inspection of a high pressure boiler tube considered as suitable for continued service reveals a film of black magnetic iron oxide thick enough to polarize the tube metal against continued corrosion, and thin enough to avoid significant impairment of heat transfer. Boiler water conditioning is designed to stabilize this protective film. The degree of success of conditioning at Oswego can be expressed by stating that in 40 boiler-years experience with the first three units there was not a single tube failure from internal corrosion. The experiences with the company's fourth and newest unit were described by Finnegan.[3]

Under normal operating conditions, dissolved oxygen plays a minor role in the direct corrosion of boiler metal. By means of continuous oxygen concentration recordings, a dissipation of dissolved oxygen was observed from a maximum of 0.005 ppm in the feedwater leaving the deaerating heater, to 0.002 ppm at the economizer inlet. It is logical to assume that this trace of dissolved oxygen will be consumed in oxidizing the surfaces of the economizer before it enters the upper drum of the boiler.

The term "bonded oxygen" is used to define the combined oxygen in water. In the reaction between iron and pure oxygen-free water, the latter functions as an acid with displacement of hydrogen by the metal and the precipitation of an oxide. Although the chemistry of the reaction is not clearly understood, it is considered that the oxygen of the water molecule is free to corrode boiler metal only when the protective film is broken due to a localized failure to maintain uniform water concentrations of proper alkalinity and dissolved salts. Usually, the corrosion from this source of oxygen is very slow, and promotes the maintenance of the thin protective film of iron oxide.[4] The amount of corrosion can be estimated by determining the hydrogen in the steam, based on the reaction:

$$4H_2O + 3Fe \rightarrow Fe_3O_4 + 4H_2$$

Quantities of hydrogen less than 0.003 ppm are usually found.

With the maintenance of low boiler water solids, the mechanical steam scrubbers in the upper drum ensure a minimum of carryover of boiler water salts into the steam. However, contamination of the steam by vaporization of the dissolved salts defy mechanical separation, and silica has vaporization characteristics that make it necessary

to carry no more than 3.2 ppm SiO_2 in the boiler water to avoid exceeding a satisfactory 0.02 ppm in the steam.[5] Iron oxide and copper apparently also vaporize, but in quantities extremely minute. Therefore, since the quantity of corrosion products entering the boiler is much larger than that leaving, the boiler is considered the sump for the collection of nearly all corrosion products in solution or suspension within the steam and feedwater cycle.

Steam Lines

Before the use of morpholine was inaugurated, it could be assumed that pH value of the steam leaving the boiler was close to 7.0. As the steam was superheated and conducted to the turbine, the iron oxide would appear in samples and gradually increase in concentration until a maximum was found at the condenser hotwell pump discharge where the pH became 8.2 to 8.5. The pH phenomenon is in accordance with the findings of Corey and Finnegan[6] who made a study to obtain information regarding the fundamental corrosion reaction of pure water on iron. This study demonstrated that when iron rods are submerged in oxygen and carbon dioxide free water within an iron vessel, the solution reaches equilibrium at a pH value of approximately 8.3 in 20 days, produces black magnetic Fe_3O_4, and several atmospheres of hydrogen. If the tests had been conducted at boiler temperatures, a change would have been expected in the rate of reaction, but not in the reaction itself. The addition of morpholine, therefore, reduces the hydrogen ion concentration nearly 10-fold, and thereby affects an environment in which iron is less soluble.

The corrosion of steam line surfaces either from bonded oxygen or from low pH effect is not considered particularly

serious since the solution of iron is uniform rather than concentrated in a small area. The product of corrosion, however, justifies consideration in that there is a tendency for the oxide to deposit on orifices and instrument feeler lines to the degree where maintenance is sometimes required. The product also contributes to the total sum that eventually reaches the boiler.

Prior to the pH adjustment of the steam, the valve stems of the turbine stop valves became discolored with a very dense layer of Fe_3O_4. The application of morpholine cured an epidemic of sticking valves by reducing the formation of this deposit.

Turbine

Turbine blade deposits are quartz, amorphous silica, and iron oxide as major components, with several minor compounds including cuprous and nickel oxides. The amorphous silica of samples taken from one turbine varied from 51 percent on the 18th stage, to 94 percent on the 20th. The maximum quantity of 41 percent Fe_2O_3 on the 18th stage reduced to a minor quantity on the 20th, and reappeared on the 22nd at 29 percent. The very small amount of copper and nickel, as well as of ferrous iron, could produce the greenish-yellow discoloration of the silica deposit just as these contaminants would discolor the silicate glasses.

In considering the source of these deposits, it is known that the silica can come from the boiler water through vaporization, and that the iron present is principally from corrosion of the steam line between the boiler and the turbine. Since there is no copper or nickel alloy surfaces contacting the steam in this portion of the cycle, an assumption can be made that most of these components arrived through vaporization from the boiler water. The steam is attemperated (i.e., sprayed with feedwater as part of the steam temperature control), and this probably accounts for some of the deposit. But since the total attemperating flow to the turbine is only 10 percent at full load, and since other units that do not use feedwater attemperation have similar turbine blade deposits, this source could be considered of minor consequence.

As the superheated steam passes through the turbine, temperature and pressure are reduced and moisture appears in the last stages. This moisture, traveling at extreme velocities, results in erosion and corrosion in these wet steam areas, and exposes the metal to continued attack by the extremely pure water. It is in this wet, high velocity zone that the distribution ratio of morpholine has a great advantage. By changing from a vapor in the steam to a solute in the moisture, morpholine elevates the pH value from a theoretical 7.0 to over 9.0, and provides an environment more favorable to the stability of the metal surfaces.

Condenser

Upon leaving the turbine, the steam is drawn into the main condenser which is held under a very high vacuum.

Just as the boiler acts as a sump for the accumulation of corrosion products, the condenser is a collecting point for the dissolved gases. Most of the feedwater heaters are vented to the main condenser for separation of the dissolved gases by vacuum deaeration. The gases, including ammonia, carbon

dioxide, and oxygen, cause considerable corrosion, and many of the Admiralty metal condenser tubes located in the deaerating section have failed. The vents not only contribute to the copper, nickel, and iron oxide contaminants of the feedwater by direct corrosion, but also transport corrosion products from the various heaters and vent lines to the condenser. A portion of the morpholine concentration is lost in pumping the separated gases to atmosphere and valving the aftercondenser drips to waste. For this reason, morpholine is continuously replenished to the condenser hotwell.

The condensate leaving the hotwell is believed to be extremely low in dissolved oxygen concentration. However, during its passage from the hotwell to the discharge of the hotwell pump, while under high vacuum, there is ample opportunity for air to contaminate the condensate from leaks in gage glasses, valve packings, flanges, etc. Such sources of oxygen can be reduced by mechanical maintenance. The storage water that is used to seal the hotwell pump shafts contains about 1.5 ppm oxygen, and is considered the principal source of dissolved oxygen.

Feedwater Cycle

Dissolved oxygen concentrations of samples taken from a hotwell pump discharge show about 0.020 ppm, while samples from the fourth heater discharge are about 0.008 ppm. As mentioned above, there is a similar loss of oxygen concentration between the deaerator discharge and the economizer inlet; it is assumed that there is a final consumption of oxygen upon passing through the economizer. Since there is no deaeration in these portions of the cycle, the loss in concentration is a result either of the corrosion of the confining metal, or the oxidation of copper and iron in solution to cupric and ferric oxides. Here again, metallic corrosion is fairly evenly distributed, and causes no direct problems. Indirectly, there is a major contribution to the quantity of oxides transported to the boiler.

Samples of oxides were taken from eight locations for a three-day period. The samples were cooled to room temperature and allowed to flow upwards at a rate of approximately 10 ml/minute through a cartridge of acid washed glass wool. This provided a filter to trap suspended oxides, and also an enormous glass surface for the plating out of soluble oxides. Analyses have shown that the removal of corrosion products by this method is about 90 percent complete.

The appearance of a reddish deposit is interpreted to indicate the presence of sufficient dissolved oxygen in the feedwater to produce a completely oxidized corrosion product of ferric oxide. The water transporting this red ferric oxide could lose its dissolved oxygen in passing through the deaerating heater, but in the absence of a reducing agent, the red oxide would maintain its status until it reached its final destination in the boiler, where there is a tendency to reduce the oxide to the black magnetic form at the expense of the boiler metal.[7]

The black oxide in the saturated steam and reheater samples indicates insufficient oxygen to complete the reaction from the ferrous to the ferric state. The superheated steam sample is colorless, and the author is unable to offer a logi-

cal explanation of this condition since it is felt there should be some corrosion products in the sample.

The range of total iron and copper concentration found in a series of multiple tests conducted during a three week period is shown in Table 3. In obtaining samples for this test, the water from each location was allowed to flow continuously and undisturbed in order to avoid dislodging oxides adhering to the sampling system. The samples were obtained in polyethylene bottles under acid, digested, and copper and iron determined by the neocuprine and bathophenanthroline methods.[8,9] Although these values are very small, a concentration of 0.005 ppm represents about 2 lbs entering the boiler each month. This quantity could be considered insignificant if there was assurance that it would stay suspended in the boiler water, or, if upon precipitating, it would become evenly distributed on all surfaces.

Dissolved Oxygen Scavengers

For many years chemical scavengers of dissolved oxygen have been used to augment mechanical deaeration. In recent years, hydrazine has become commercially available, and several power companies have employed it, reporting various degrees of its effectiveness.

By means of a dissolved oxygen recorder, hydrazine was evaluated in concentrations up to three times the theoretical quantity required; it was found that there was practically no reduction of dissolved oxygen. The author plans to renew his studies, employing various catalysts in an effort to promote a fast, complete, low temperature reaction at the hotwell portion of the feedwater cycle.

Sodium sulfite apparently has a greater affinity for dissolved oxygen than hydrazine, but the author is hesitant to use this reducing agent since it would increase total solids in the boiler water. In addition it has a tendency, at higher temperatures, to produce hydrogen sulfide and sulfur dioxide, resulting in severe corrosion of copper and nickel alloy heat exchangers.

It is logical to assume that if dissolved oxygen could be eliminated from the feedwater at the hotwell pump discharge, the piping and heaters in the cycle would tend to become immune to to active corrosion by the formation of a stable black magnetic iron oxide. The corrosion products and their transportation to the boiler would be reduced to a minimum.

Abnormal Conditions

Thus far, attention has been centered on corrosion at normal, full load operation. It would be unwise, however, to ignore three conditions resulting in

TABLE 3—Range of Iron and Copper Concentrations

LOCATION	ppm Fe	ppm Cu
Hotwell Pump Discharge...	.002-.003	.000-.001
3rd Heater Discharge......	.005-.006	.008-.019
Boiler Feed Pump Discharge	.003-.009	.013-.017
Economizer Inlet..........	.002-.005	.002-.007
Saturated Steam..........	.002-.003	.000-.001
Superheated Steam........	.003-.005	.004-.006
Reheater Inlet............	.000-.003	.000-.001
Reheater Outlet..........	.019-.060	.000-.012

serious corrosion over which the chemist has a minimum of control and influence.

1. Considerable damage is done to new boilers in the last stages of erection when it is necessary to conduct several hydrostatic tests before achieving a tight system. Alternate wetting and drying of tube surfaces are ideal for starting corrosion cells that may or may not be passivated when the unit goes into service.

2. Upon completion of installations of a new unit, contractors report their heaters, tanks, piping, etc., as clean and ready for service. Through experience, it has been learned that there is a vast difference between the standards of cleanliness accepted by the contractors and by the operators. Contractors apparently have very little conception of the damage caused by a small quantity of weld beads, rods, slag, and other foreign material left in the circuits.

3. A third condition causing serious damage to high pressure steam plants result from week-end and holiday "economy" outages. These shut-downs occur when the system load demand falls well below the system capacity.

Then units with the best efficiency are retained on the line and the older, less efficient units are shut down. During the period when the unit is down and also while it is being restored to service, there is no provision to deaerate the feedwater, and a high concentration of dissolved oxygen is available to corrode all metal surfaces. Auxiliary equipment is especially subject to serious corrosion wherever there is atmospheric condensation.

Conclusion

A review has been made of some aspects in the formation, transportation, and deposition of corrosion products within the cycle of a high pressure steam plant. The interpretations and observations of the process submitted reveal the general ignorance concerning the fundamentals of high- temperature corrosion. However, the experience gained in the design and operation of the new supercritical boilers will benefit all power plant chemists.

The chemist should emphasize the damage to power plants during erection, low load operation, and shut-down periods.

References

1. C. Jacklin. Experimental Boiler Studies of the Breakdown of Amines. *Trans. ASME*, 77, No. 4, 449 (1955) May.
2. F. G. Straub. Comparison of the Action of Ammonia, Amines, and Hydrazine in Reducing Metal Pick Up in the Condensate and Feedwater of Closed Cycle Steam Power Plants. Proc. 14th Water Conference, Engineer Society of Western Pennsylvania, page 91.
3. T. J. Finnegan. A Corrosion Problem in Large Steam Generating Stations. *Corrosion*, 13, 405t (1957) June.
4. C. E. Kaufman, W. H. Trautman and W. R. Schnarrenberger. Action of Boiler Water on Steel—Attack by Bonded Oxygen. *Trans. ASME*, 77, No. 4, 423 (1955) May.
5. F. G. Straub and H. A. Grabowski. Silica Deposition in Steam Turbines. *Trans. ASME*, 67, No. 5, 309 (1945) Ju'y; C Jacklin and S. R. Browar. Correlation of Silica Carryover and Solubility Studies. ASME paper S1-A-91, Nov. 25-30, 1951.
6. R. C. Corey and T. J. Finnegan. The pH, Dissolved Iron Concentration and Solid Product Resulting from the Reaction Between Iron and Pure Water at Room Temperature. *ASTM Proceedings*, 39, 1242 (1939).
7. F. G. Straub. Comparison of the Reducing Power of Sodium Sulfite and Hydrazine in the Steam-Water Cycle of Steam Power Plants. *Combustion*, 28, No. 7, 34 (1957).
8. G. F. Smith, W. H. McCurdy, Jr. and Harvey Diehl. The Colorimetric Dete mination of Iron in Raw and Treated Municipal Water Supplies by Use of 4:7-Diphenyl-1:10-Phenanthroline. *The Analyst*, 77, 418-422 (1952) Aug.
9. G. F. Smith and W. H. McCurdy, Jr. 2,9-Dimethyl-1:10-Phenanthroline, New Specific in Spectro-Photometric Dete mination of Copper. *Analytical Chemistry*, 24, 371-373 (1952) February.

Microbiological Deterioration
Of Buried Pipe and Cable Coatings*

By F. E. KULMAN

Introduction

PROTECTIVE COATINGS are applied to underground pipes and cables to prevent corrosion and hence failure of the metal. Experience has shown that the insulation resistance of the coatings decreases with time. In some cases the decrease is caused by the absorption of soil water by the coating. In other cases the coating is deformed by mechanical pressures of hard soil particles, rock and bed blocks. Chemical changes and microbiological deterioration probably account for some damage. It is evident that if the coating loses its insulating properties, the electrolyte will reach the metal surface and corrosion underneath the coating will occur. An additional investment for cathodic protection is needed therefore to protect the pipe electrically at low-resistance points in the coating. In many cases reliance for protection is placed on the coating alone, since cathodic protection may be impractical or expensive to install or operate.

There is, therefore, a need for pipe and cable coatings which will better withstand the various kinds of damage which continued exposure to the soils and underground ducts brings on. As the result of increasing experience, better coatings are being developed. In this development it is necessary to be certain that the coatings will be immune to deterioration by soil microorganisms as well as being otherwise acceptable.

The particular work reported herein describes a recently completed investigation of the resistance of some existing coating materials to soil microorganisms. The scope of the investigation excluded deterioration by electroendosmosis and by chemical and mechanical agents.

Existing Coating Materials

Coatings have been used in New York City for approximately 25 years to provide corrosion protection to underground lead sheath cables and buried steel gas pipes in certain corrosive areas.

The first cable coatings consisted of two spiral wrappings of asphalt-impregnated duck tape wound over the lead sheath of the cable which had been coated previously with a layer of asphalt. This type of cable, of which 75,000 feet had been installed in the most corrosive soil areas, still provides protection in the ducts where it is installed. Only one case of failure of this cable because of sheath corrosion has been reported. However, when it is necessary to remove the cable for reasons other than corrosion, the duck tape is usually rotted and adherent to the duct wall and occasionally it obstructs the withdrawal of the cable. Therefore the use of this cable was abandoned.

★Submitted for publication September 3, 1957.

F. E. KULMAN is a senior engineer with Consolidated Edison Company of New York, Inc. He has been employed by this firm for 31 years, most of which time has been devoted to investigation and mitigation of electrolysis and corrosion problems on underground cable and gas piping systems. Mr. Kulman received EE and MEE degrees from Polytechnic Institute of Brooklyn. He is a member of NSPE and NACE and has contributed papers on corrosion to a number of technical organizations.

Beginning in 1939, a reinforced rubber jacket applied by the cable manufacturer was used over the lead sheath to provide protection. This consisted of two layers of rubber tape with a cotton fabric backing, wrapped with the rubber faces together, and vulcanized to give continuous adherent coating. Later the rubber was replaced by neoprene and cable with a reinforced neoprene jacket now is being used in corrosion areas.

Since 1947, pipe-type cables have been installed in steel pipe protected by an extruded asphalt mastic coating. The asphalt mastic is composed of asphalt, sand and a fine filler.

Steel pipes for gas distribution have been coated since 1935 with heated coal tar enamels applied to cleaned and primed surfaces, followed by an impregnated asbestos felt wrap, and either a kraft paper bonded to the asbestos with the enamel, or a coating of white-wash. The fully plasticized coal tar enamels have been used since 1946. Since 1950, a layer of glass felt has been incorporated into the enamel layer as a reinforcement under the asbestos shield.

Investigations of Coating Deterioration by Others

The rotting of organic materials buried in the soil has been investigated with increased attention during the past 15 years. Starkey and Wight[1] made preliminary soil burial tests on pipe-wrapping tapes, the composite structure of which included a cellulose acetate film, cotton fabric and a petroleum wax. The criteria for deterioration were loss of

Abstract

Visual tests of nutrient inertness on 28 coating materials showed that only half were inherently inert to the attack of four selected species of fungi. One of the materials had fungistatic properties. The visual tests were useful for screening materials for more extensive testing.

Tensile tests of coatings buried in soil showed that polyethylene and polyvinyl chloride were immune to deterioration, that a neoprene coating was infested with fungi and that a tar-impregnated cotton fabric was deteriorated to a marked extent in inoculated soil. By the use of "sterilized" soil, the influence of the physical and chemical properties of the soil on coatings can be separated in part from the action due to soil micro-organisms.

Insulation resistance measurements on coated pipes and cables buried in soil boxes gave sensitive indication of coating changes. Because of difficulty in maintaining a soil "sterile" it is not possible to separate the effects of moisture absorption and microbiological deterioration in lowering the insulation resistance. However, tests on various modifications of the soil showed that deterioration of neoprene coatings occurred in soils inoculated with aggressive fungi.

Coal tar enamel coatings resisted deterioration and out-performed asphalt mastic and petroleum wax coatings.

Polyethylene and polyvinyl chloride coatings resisted deterioration and showed better performance than neoprene coatings.   **3.3.4**

weight and loss of tensile strength in the tape. It was found that the tapes buried in aerobic soil (fertile sandy loam) suffered serious deterioration, more so than those in waterlogged soil. The damages to the materials were attributed to soil microorganisms. Discoloration of the tapes was attributed to fungi.

A soil burial test to measure the degree of deterioration of textiles under soil cover is described in a tentative standard by the American Society for Testing Materials,[2] and specifies tensile strength determination for judging resistance to microorganisms. This method was used by the Department of the Interior as the basis for investigating materials for canal linings.[3] The report of these tests contains a critical review of selected literature on the effect of microorganisms on hydrocarbons and their derivatives and on cellulose materials. A general conclusion of the report was that "there is no material familiar to the many investigators that can completely resist the attacks of microorganisms and their enzymes in the soil formation process which, though it may require many years, reduces all materials to the same level."

In a paper explaining the failure of rubber-insulated control wires, Blake and Kitchin[4] showed that the insulation resistance of wires covered with natural rubber or synthetic rubbers and buried in garden soil decreased to one-millionth of the initial values in four months.
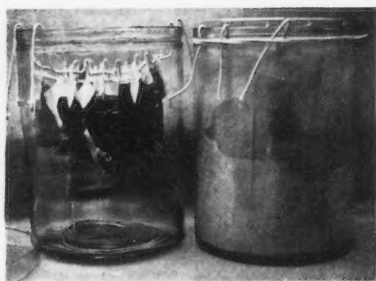
Figure 1—Nutrient inertness test. The absorbent paper has been removed from the jar at left to show the coating specimens.

Similar wires submerged in sterile soil or in water showed no reduction in insulation resistance. The deterioration was most rapid in damp, aerobic soils and least so in dry or completely wet soils. Natural rubber was more vulnerable to deterioration than GR-S (butadiene and styrene copolymer) and butyl rubber. The deterioration, which was not accompanied by visible surface appearance of damage, was attributed to fungi in the soil.

In the later report[5] these investigators described the micropores caused by the fungi in the insulation wall. The micropores, it was found, occurred in synthetic materials in which the base hydrocarbon was stable but the additives, scattered in a random manner in the synthetic, were vulnerable to the fungi. Streaks of microbe food constituted the imperfections which, upon being consumed by the fungi, developed into micropores which ultimately penetrated the insulation wall.

In their latest paper[6] the investigators identified two species of fungi which were found to bore through GR-S insulations. Laboratory tests showed that thorough mixing of the GR-S ingredients before application to the wire would increase the life of the insulation by 50 percent. To obtain a more nearly perfect insulation, therefore, a stable GR-S compound was developed by addition of a fungicide. Butyl and neoprene were found to possess relatively great inherent stability against fungi so that theoretically compounds of these materials might be made completely fungus-resistant by perfect processing alone. Tests on neoprene gave inconclusive results except to indicate that white neoprene containing a hard clay filler was inferior to the black neoprene and thus more vulnerable to fungus attack.

Research during World War II on the deterioration in tropical regions of electrical equipment for military use emphasized the importance of fungi in this deterioration. This research led to the development of accelerated laboratory tests in which visual observations of fungus growth are made to determine whether non-metallic materials in electrical assemblies are nutriently inert to the fungus attack, and whether these materials have fungistatic properties which would prohibit the growth of fungi on the surfaces of the materials. Such tests were used in the early phase of the company's investigation.

Methods Selected for Testing for Deterioration of Coatings

Consolidated Edison Company of New York initiated a laboratory study of coating deterioration in 1949, utilizing the services of a specialized laboratory for the microbiological phases of the investigation. This work was the outgrowth of a study of bacterial corrosion of metal.[7] Three kinds of laboratory tests were made on organic coating systems or components to determine the microbiological damage, as follows:

1. Visual tests of nutrient inertness and fungistatic effectiveness.

2. Soil burial of coatings with tensile strength as the criterion.

3. Soil burial of coated pipes and cables with insulation resistance as the criterion.

Visual Tests

Visual Test of Nutrient Inertness

This test which was made with 28 coating materials was designed by the Bureau of Ordnance of the Navy Department to demonstrate whether insulating materials or components furnish nutrients to support the growth of fungi. The test indicated: (a) whether fungi could grow on the material alone and therefore derive nutriment from the material, and (b) whether lack of growth of fungi on test samples might have been due to fungistatic components in the sample. In order for the material to pass this test it was required that fungus growth should not occur on test samples exposed separately, but should extend over samples attached to nutrient cotton blanks. This double requirement appeared essential for testing for nutrient inertness since otherwise slight or temporary fungistatic effectiveness, insufficient to qualify under the test for fungistatic effectiveness might have given an apparent qualification under nutrient inertness.

The test was run in small covered glass chambers with walls and bottom lined loosely with moist absorbent paper. Figure 1 is a photograph showing a glass chamber as removed from the incubator, and another glass chamber with the absorbent paper removed to permit visual observation of the specimens. Because of the inadequate amount of some sample materials, and in order to keep the test uniform, six samples, rather than the eight normally required, were used for each material. The samples were cut to approximately one-inch by three-inch dimensions. Three samples were exposed separately and three were exposed with portions of cotton string blanks closely attached. The completed setup was inoculated with a suspension containing the spores of the following species of fungi:

Micro-Organism	American Type Culture Collection
Aspergillus niger	9642
Aspergillus flavus	9643
Penicillium luteum	9644
Trichoderma T-1	9645

The glass chambers were then maintained in an incubator at 28 C and 95

TABLE 1—Nutrient Inertness Tests on 28 Coating Materials

MATERIAL	Side of Material Tested	Surface Growth Percent	Rating*	Extended Growth —mm	Rating**
Plasticized Coal Tar Enamel	Outside	0	Pass	3	Pass
Glass Felt Coated with Enamel	Back	0	Pass	1	Pass
	Enamel Side	0			
Asphalt Mastic	Both Sides	0	Pass	1	Pass
Glass Fabric	Both Sides	0	Pass	1	Pass
Rubber Insulation, 600 V. Cable	Both Sides	0	Pass	0	—
Reinforced Neoprene Jacket	Both Sides	0	Pass	0	—
PVC Press. Sens. Tape, 10 mil	Both Sides	0	Pass	0	—
PVC Press. Sens. Tape, 7 mil	Both Sides	0	Pass	1	Pass
Polyethylene Press. Sens. Tape, Gray	Both Sides	0	Pass	2	Pass
Polyethylene Press. Sens. Tape, Black	Both Sides	0	Pass	2	Pass
Extruded Neoprene Jacket	Outer	0	Pass	3	Pass
	Inner	2			
Plasticized Coal Tar Enamel	Enamel	0	Pass	9	Pass
bonded to asbestos felt	Felt	5	Fail		
Plasticized Coal Tar Enamel	Enamel	0	Pass	7	Pass
containing fiber glass and bonded to asbestos felt	Felt	15	Fail		
Polyethylene Cable Sheath	Both Sides	1	Pass	1	Pass
Fibre Glass	Both Sides	2	Fail	3	Pass
Neoprene Coated Bolt	Both Sides	5	Fail	—	—
Pigmented Polyethylene Cable Jacket	Both Sides	10	Fail	15	Pass
Petroleum Wax Coating	Outer	10	Fail	2	Pass
	Inner	0			
PVC Press. Sens. Tape, 10 mil	Outer	0–25	Fail	5	Pass
	Inner	25–80			
Petroleum Wax	Both Sides	25	Fail	10	Pass
Petroleum Wax Coating	Outer	25–80	Fail	20	Pass
	Inner	10–80			
Wax Impregnated Cotton Tape	Both Sides	50	Fail	25	Pass
Coal Tar Coated Cotton Fabric	Smooth Side	5	Fail	20	Pass
	Rough Side	75			
PVC Press. Sens. Tape, 10 mil	Inner	80	Fail	5	Pass
Wax Impregnated Cotton Tape	Both Sides	75	Fail	25	Pass
Felted Glass Pipe Wrap	Dull Side	100	Fail	100%	Pass
	Gloss Side	80			
Wax Impregnated Cotton Tape	Both Sides	100	Fail	25	Pass
Extruded Cellulose Acetate Butyrate	Both Sides	100	Fail	25	Pass

* For passing rating, fungus growth perceptible to the naked eye shall not cover more than about 2 percent of the surface area of any sample exposed separately.
** For passing rating, fungus growth perceptible to the naked eye shall extend to a distance of at least 1 millimeter along the test sample, measured from the point of contact with the attached blanks. (Absence of such growth indicates that the sample is somewhat fungistatic and that data on nutrient inertness cannot be obtained by this test).
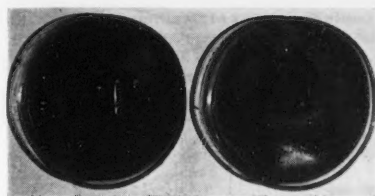
Figure 2—Fungistatic effectiveness test on coal tar enamel (left) and petroleum wax (right).
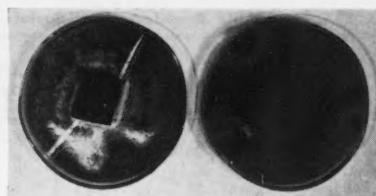
Figure 3—Fungistatic effectiveness test on rubber insulation (left) and neoprene sheath (right) of network cable.
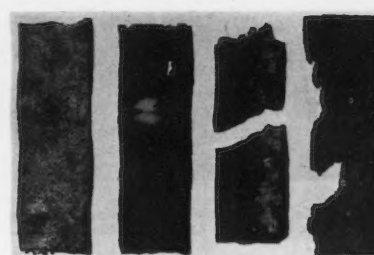
Figure 4—Tar impregnated tapes buried 12 months in inoculated soil.

to 98 percent relative humidity. Observations were made for fungus growth after incubation for two, four and six weeks. The results of some of these observations are presented in Table 1.

It is noted that only half of the 28 materials tested in 1949 were inert to the fungi. This short-time test was found to be useful for screening materials for more extensive testing.

Visual Test of Fungistatic Effectiveness

This test was designed to demonstrate the presence of fungus resistance resulting from a chemical sufficiently toxic and diffusible to prohibit fungus growth on, or touching the material under test. It may be performed as a test of innate fungistatic potency (inherent in the material) or a potency provided by some chemical incorporated during manufacture. The test procedure was similar to that specified in paragraphs 4.6.16.1-6 of Reference 8.

The test was made on the 28 materials in standard Petri dishes with approximately 25 ml of a nutrient test medium. Three samples of each material, cut into one-inch dimensions, were placed in the center of individual dishes of solidified medium, and a one milliliter portion of the spore suspension used in the nutrient inertness test was pipetted over the surface of the sample and agar medium. The dishes were incubated at 28 C for 14 days.

Observations were made for fungus growth after incubation for 7 days and 14 days. The results of some of these observations are given in Table 2. Figure 2 shows the absence of growth on a coal tar enamel specimen and growth over the edges of a petroleum wax coating.

Figure 3 shows that rubber insulation of the 600-volt network cable inhibited the growth of fungi and that the neoprene sheath did not. It is noted from Table 2 that only one of the materials was fungistatic. This was the rubber insulation of the rubber-insulated network cable. The over-all results of the nutrient inertness and fungistatic effectiveness test also are recorded in Table 2.

Soil Burial of Tensile Specimens

The loss of tensile strength of samples buried in fertile soil has been adopted as a criterion of microbiological deterioration of materials and its determination for textiles is specified in ASTM Test D684-45T.[2]

In the present investigation this method was adapted to the testing of polyethylene, polyvinyl chloride and neoprene coatings of lead covered cables, and a coal tar impregnated cotton tape, for microbiological damage resulting from soil burial.

The specimens were prepared by removing the coating from the cables and stamping out 48 specimens (including controls) of each material with the standard die, to give a tensile test piece 2 inches by ½ inch exclusive of the enlarged ends. The tensile tests were made in accordance with ASTM Specification D412-41.[9] The impregnated tape was cut into rectangles 4 by 6 inches in dimension for burial and tensile testing.

The soil bed containing the specimens consisted of an organic porous soil, to a depth of five inches, contained in a wooden bench in a greenhouse. The soil was enriched by the addition of the following aggressive fungi:

Micro-Organism	American Type Culture Collection
Aspergillus niger	9642
Aspergillus flavus	9643
Penicillium luteum	9644
Trichoderma T-1	9645

Temperatures were maintained between 15 C and 30 C. Water was added periodically to the soil to replace that lost through evaporation. These conditions provided an environment comparable to three or more seasons outdoors under a temperate climate in accelerating the microorganic attack.

For each coating, control specimens were placed in "sterilized" soil contained in quart size glass jars previously sterilized. The soil was sterilized in an autoclave for one-half hour by steam at 15 psig pressure before being placed in the glass jars. The control specimens were partially sterilized by washing with alcohol. After the controls were covered by the "sterilized" soil, the jars were capped to exclude entrance of microorganisms from the air.

Specimens of coatings were removed from the inoculated and "sterilized" soils after 1 to 2, 6 and 12 months. These were observed for visual evidence of fungus growth and subjected to tensile tests.

Inspection of Specimens in Inoculated Soil

After 12 months' burial in inoculated soil, the exterior surfaces of polyvinyl chloride and polyethylene showed no visible change. The inner surfaces gave some evidence of the presence of fungal hyphae. A few roots were closely appressed to the inner surface. There was a deposit of a creamy white granular material on the inner surface. Microscopic examination did not identify it as mycelial (fungus) growth though it

TABLE 2—Fungistatic Tests on 28 Coating Materials

MATERIAL	Fungistatic Effectiveness Test			Over-all Rating	
	Extent of Surface Growth over Edge of Specimen	Rating*	Nutriently Inert	Fungistatic
Plasticized Coal Tar Enamel	2 mm	Fail	Yes	No
Glass Felt Coated with Enamel	Growth on edges	Fail	Yes	No
Asphalt Mastic	3 mm	Fail	Yes	No
Glass Fabric	Complete surface growth	Fail	Yes	No
Rubber Insulation, 600 V. Cable	None. Zone of inhibition	Pass	—	Yes
Reinforced Neoprene Jacket	4 mm	Fail	—	No
PVC Press. Sens. Tape, 10 mil	5 mm	Fail	—	No
PVC Press. Sens. Tape, 7 mil	7 mm	Fail	Yes	No
Polyethylene Press. Sens. Tape, Gray	2 mm	Fail	Yes	No
Polyethylene Press. Sens. Tape, Black	2 mm	Fail	Yes	No
Extruded Neoprene Jacket	1 mm	Fail	Yes	No
Plasticized Coal Tar—enamel bonded to asbestos felt	1 mm on enamel side	Fail	Yes**	No
Plasticized Coal Tar Enamel containing fibre glass and bonded to asbestos felt	1 mm on enamel side	Fail	Yes**	No
Polyethylene Cable Sheath	5 mm	Fail	Yes	No
Fibre Glass	Complete surface growth	Fail	No	No
Neoprene Coated Bolt	3 mm	Fail	No	No
Pigmented Polyethylene Cable Jacket	Growth over 50 percent	Fail	No	No
Petroleum Wax Coating	3 mm	Fail	No	No
PVC Press. Sens. Tape, 10 mil	7 mm	Fail	No	No
Petroleum Wax	Complete surface growth	Fail	No	No
Petroleum Wax Coating	20 mm	Fail	No	No
Wax Impregnated Cotton Tape	Complete surface growth	Fail	No	No
Coal Tar Coated Cotton Fabric	5 mm	Fail	No	No
PVC Pressure Sens. Tape, 10 mil	35 percent back shows surface grown, 90 percent adhesive shows growth	Fail	No	No
Wax Impregnated Cotton Tape	25 percent surface growth	Fail	No	No
Felted Glass Pipe Wrap	Complete surface growth	Fail	No	No
Wax Impregnated Cotton Tape	Complete surface growth	Fail	No	No
Extruded Cellulose Acetate Butyrate	Surface growth	Fail	No	No

* For passing rating on fungistatic effectiveness test no perceptible fungus growth shall occur on any of the test samples.
** Rating applies to plasticized coal tar enamel, not to asbestos felt.
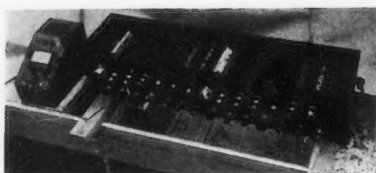
Figure 5—Soil box containing 28 coating specimens and guard circuit before completely filling with soil.
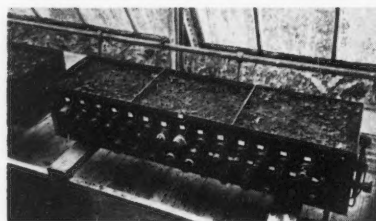
Figure 6—Soil box completely filled with soil.

TABLE 3—Effect of Soil Burial on Tensile Properties of Coatings

	Inoculated Soil			Sterilized Soil		
	Load Avg. Lbs.	Elong. Avg. %	Set Avg. %	Load Avg. Lbs.	Elong. Avg. %	Set Avg. %
As Received:						
Polyvinyl Chloride.................(3)*	86	185	20	86	185	20
Polyethylene I......................(3)	62	85	8	62	85	8
Polyethylene II.....................(3)	65	100	8	65	100	8
Reinforced Neoprene................(3)	59	255	10	59	255	10
Tar-impregnated Fabric............(6)	56	10	6	56	10	6
After 1 to 2 Months' Burial:						
Polyvinyl Chloride.................(6)	110	155	15	92	181	10
Polyethylene I......................(5)	68	87	8	68	75	7
Polyethylene II.....................(6)	68	80	8	63	66	13
Reinforced Neoprene................(6)	31	175	9	30	138	7
Tar-impregnated Fabric............(6)	40	9	7	68	12	7
After 6 Months' Burial:						
Polyvinyl Chloride.................(5)	116	147	10	108	170	13
Polyethylene I......................(5)	68	93	18	64	93	12
Polyethylene II.....................(5)	67	97	16	62	100	15
Reinforced Neoprene................(5)	35	167	7	30	228	12
Tar-impregnated Fabric............(3)	20	0	—	61	0	—
After 12 Months' Burial:						
Polyvinyl Chloride.................(5)	107	150	16	90	140	7
Polyethylene I......................(5)	64	80	16	73	95	12
Polyethylene II.....................(5)	68	80	17	62	85	12
Reinforced Neoprene................(5)	29	165	10	31	190	5
Tar-impregnated Fabric............(4)	—	—	—	34	6	—

* Number in parentheses indicates number of specimens tested for tensile strength and elongation.

may have been in part a residue of previous growth activities of fungi. There is also a possibility of its origin as an oil film between the lead sheath and the jacket.

Neoprene was very flexible or limp compared with the initial observations. These specimens showed definite evidence of fungal mycelia growing on the exterior and inner surfaces. Roots were closely appressed to these surfaces. The whitish granular material was abundant on the inner surface.

The coal tar impregnated fabric tapes had undergone the greatest deterioration of the five materials under test. Two specimens were intact, four had fragments of the edges lost or cracks across the specimens and two had separated into irregular parts with the rotting of the fabric. A photograph of four of the specimens is shown in Figure 4. While at the time of observation there was little or no direct evidence of fungal mycelia, there were many roots appressed to the surfaces, especially the most tarred surface.

Inspections of Sterile Controls

After one and two months' burial in "sterilized" soil, there were no visible changes in any of the control specimens, nor evidence of fungal growth.

After six months' exposure there were several observations of interest. The specimens of polyvinyl chloride and polyethylene exhibited no evidence of attack by fungi nor presence of them. The polyethylene controls had some bluish-white bloom on the inner surface. The flexibility of the polyethylene specimens appeared to have decreased.

The reinforced neoprene controls had considerable white mold, especially on the exterior fabric surface. (Since these specimens were not completely sterilized before placing them in the sterilized soil and jars, it is likely that the fungi were resident on or in the materials. The soil environment promoted the active development of spores or mycelia.)

The coal tar impregnated fabric controls showed a slight amount of fibrous growth on the inner surface. One of these controls was broken, apparently during removal.

After one-year burial, the appearance and condition of the controls followed those noted at the six months' period. Polyethylene either was unchanged in

outward appearance, or showed bluish white discoloration on the outer surface of one control and on the inner surface of others. A white granular material was present on the interior surface of two controls.

Neoprene was very flexible or limp compared with the original sample. Three specimens had considerable areas with a white, filamentous growth. This was especially prominent on the outer fabric surface.

The coal tar impregnated fabric controls showed no evidence of fungus growth on the surface. The tar surface was shiny. All specimens were intact but exhibited greater brittleness than the original material.

Physical Tests

The results of the tensile, elongation and set tests are shown in Table 3 for the specimens in inoculated and sterile soils. This table shows average values after burial periods of 1 to 2 months, 6 months and 12 months.

Discussion

Considerable spread was observed in the individual results of the physical tests on the same materials. This variation probably resulted from variations in thickness of the coatings, non-uniform biological influence, and other factors. The number of replicates was relatively small, usually four or five for the tensile and elongation tests, and two for the set tests. For the more durable materials such as polyvinyl chloride, polyethylene and neoprene, the microbiological effect on deterioration is not easily determined because of the obscuring effect of other factors. However, it is apparent that the tar-impregnated fabric deteriorated much more rapidly in the inoculated soils than in the pre-sterilized environment.

Certain pertinent facts are brought out by the soil burial tests. The polyvinyl chloride and polyethylene coatings were completely or nearly free of infestation with fungi in inoculated and sterile soils. The reinforced neoprene jacket was infested in the inoculated and sterile soils and the material had become very flexible. The coal tar impregnated tape remained visibly unaffected

in the "sterile" soil but was deteriorated to a marked extent in the inoculated soil. In the open greenhouse bench soil, only two of eight tape specimens remained intact after 12 month's burial.

It appears that the accelerated soil burial tests permit separating microbiologically resistant coating materials from those that are subject to attack by soil microorganisms. They also may give relative data on the degree of resistance. By the use of sterilized soil, the influence of the physical and chemical properties of the soil on deterioration of coatings can be separated in part from the action due to soil microorganisms. A study of satisfactory methods for securing at least surface sterilization of the samples without alteration of physical properties should permit more complete separation of soil and microorganic effects.

Insulation Resistance of Coated Pipes and Cables

The tests previously described were made on coatings or portions of coatings not attached to a metal substrate. This permitted microbiological attack to occur on both faces of the coating. In the third series of tests, coated pipes and cables were buried in soil boxes and insulation resistance was selected as the criterion of deterioration.

In August 1949, seven soil boxes were filled with soil removed from a field site known to be corrosive toward steel pipe. The soil is best described as a mixture of brown, sandy loam and clay, with a moisture content of 18.2 percent, organic matter content of 6.0 percent, and pH value of 6.1. Numerous analyses of the chemical and bacterial content of the soil had been made previously and were published in Reference 7 in which the location was identified as site IV.

Before placing the specimens, the soil from field site IV was given individual treatment for each box as follows:

Box	Treatment
A	Corrosive soil in its natural state as removed from the ground.
B	Steam-sterilized soil.
C	Soil inoculated with anaerobic bacteria and kept in a waterlogged state.

D   Soil inoculated with aerobic bacteria and kept in a normally moist state.

E   Moist soil inoculated with aggressive fungi and adjusted to pH 6.1–6.5.

F   Moist soil inoculated with fungi as in (E) but adjusted to pH 8.0.

G   Soil inoculated with fungi as in (E) and (F), at pH 6.1–6.5, and kept in a waterlogged state.

Steel pipes of ¾-inch nominal diameter were coated by experienced coating applicators with: (1) asphalt mastic, (2) coal tar enamel and asbestos felt, and (3) petroleum wax with asbestos wrapper and Kraft paper. The pipes were cut into 18-inch lengths for burial in the boxes. Similarly, one-inch diameter lead pipes jacketed with polyethylene (2 grades), polyvinyl chloride and reinforced neoprene were cut into 18-inch lengths and buried. Four samples of each coating were buried in each of seven boxes in accordance with the replication plan shown in Table 4.

The construction of the coatings was as follows:

P-1. **Asphalt Mastic:** A mixture of asphalt, sand and filler, heated and hand applied on primed pipe to a nominal thickness of ⁷⁄₁₆ inch. The finished coating was covered with whitewash. Because of coating eccentricity the high spots were turned down in a lathe before burying the pipes.

P-2. **Coal Tar Enamel:** A ³⁄₃₂-inch coating of coal tar enamel applied hot to primed pipe and followed by a helical wrapping of 14-pound impregnated asbestos felt and a wrapping of Kraft paper. The Kraft paper was removed before burying the pipes.

P-3. **Petroleum Wax:** A ¹⁄₃₂-inch thickness of soft microcrystalline petroleum wax applied hot and followed by a helical wrapping of reinforced asbestos wrapper. A hot application of a hard petroleum wax was applied over the asbestos wrapper and was followed by a wrapping of Kraft paper.

C-1. **Pigmented Polyethylene I:** 100 mils thick, extruded on a 1-inch diameter lead sheath cable.
Pigmented Polyethylene II: 100 mils thick, extruded on a 1-inch diameter lead sheath cable.

C-2. **Polyvinyl Chloride:** 100 mils thick, extruded on a 1-inch diameter lead sheath cable.

C-3. **Reinforced Neoprene Jacket:** 100 mils thick. Two neoprene faced cotton tapes were wound helically on a 1-inch diameter lead sheath cable, with the neoprene faces adjacent. The coating was cured by vulcanizing on the cable.

The pipes were placed horizontally in the soil boxes with their ends protruding through micarta bushings placed in the side walls of the box. The space between the pipe and bushing was filled with "Duxseal," a non-hardening, plastic waterproofing material. Guard rings were placed near the ends of the specimen to reduce the error in the insulation resistance measurement caused by surface leakage of current. The soil boxes were kept in the desired moist or
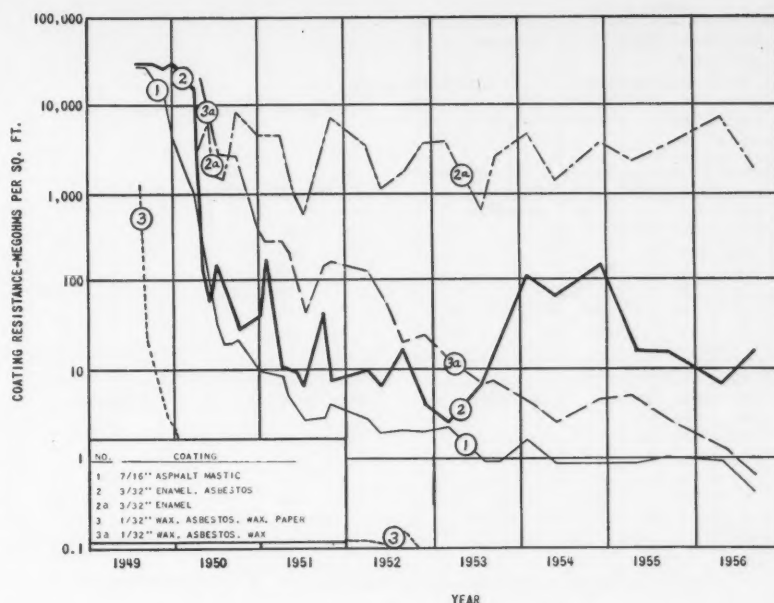
Figure 7—Insulation resistance of pipe coatings in soil boxes (median values plotted).

NO.	COATING
1	7/16" ASPHALT MASTIC
2	3/32" ENAMEL, ASBESTOS
2a	3/32" ENAMEL
3	1/32" WAX, ASBESTOS, WAX, PAPER
3a	1/32" WAX, ASBESTOS, WAX
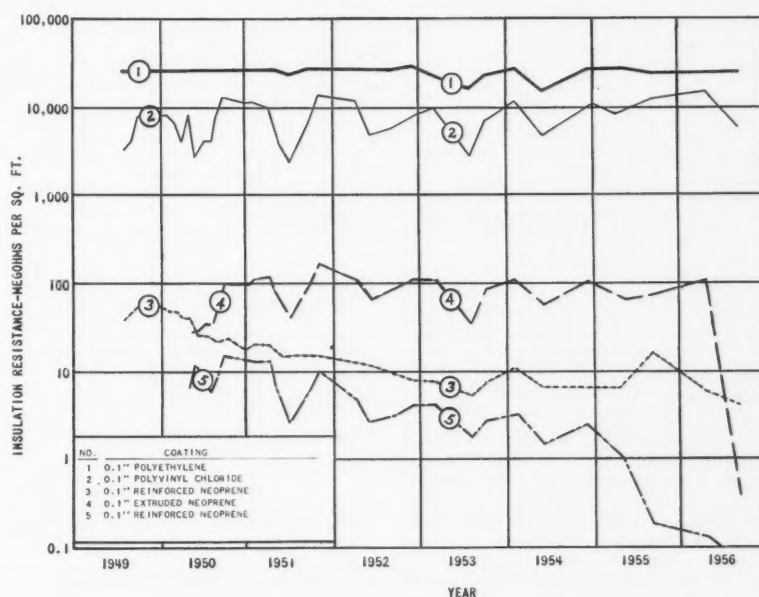
Figure 8—Insulation resistance of cable coatings in soil boxes (median values plotted).

NO.	COATING
1	0.1" POLYETHYLENE
2	0.1" POLYVINYL CHLORIDE
3	0.1" REINFORCED NEOPRENE
4	0.1" EXTRUDED NEOPRENE
5	0.1" REINFORCED NEOPRENE

waterlogged condition in an environment maintained between 15 C and 30 C. It is felt that the temperature and moisture conditions resulted in some acceleration of the microbiological attack, possibly increasing it as much as threefold in the case of the pipe coatings.

No voltage was applied to the specimens or boxes except during the short periods required to measure the coating insulation resistance. These measurements were made with a calibrated resistor and vacuum tube voltmeter, or a reflecting type galvanometer, in series with the coating in the measuring circuit. The measurements were made at intervals of one month or more. De-

creases in insulation resistance were sought for as indications of coating deterioration.

Figure 5 is a photograph of one of the boxes containing 28 coated specimens with their guard circuit, taken before the box was completely filled with soil. Figure 6 shows a box completely filled with soil.

Additional Soil Boxes Started

In May 1950, it became desirable to add two additional boxes containing the following coatings:

P-2A **Coal Tar Enamel:** A ³⁄₃₂-inch coating of coal tar enamel applied hot

Figure 9—Distribution of insulation resistance measurements of pipe coatings in soil boxes.

Figure 10—Distribution of insulation resistance measurements of cable coatings in soil boxes.

to primed pipe as in coating P-2. However, no reinforcing or shielding material was applied.

P-3A **Petroleum Wax:** A $\frac{1}{32}$-inch thickness of soft microcrystalline wax applied hot as in coating P-3 and followed by a helical wrapping of reinforced asbestos wrapper. A hot coat of hard petroleum wax was applied over the wrapper. However, the Kraft paper, normally applied, was omitted.

C-4 **Extruded Neoprene Jacket:** 100 mils thick, applied to 1-inch diameter lead pipe.

C-5 **Reinforced Neoprene Jacket:** Constructed similarly to coating C-3 previously described, but applied to lead pipe.

C-6 **Network Cable:** 500 MCM, stranded copper conductor, rubber insulated and sheathed with neoprene.

One of the additional soil boxes (H) was filled with natural soil from the field. The other box (I) was filled with natural soil inoculated with a spore suspension of aggressive fungi.

All boxes were kept in a greenhouse until November 1950, at which time they were transferred to a relatively dark indoor location in New York City.

Results of Insulation Resistance Measurements

Figures 7 and 8 show respectively, for the pipe and cable coatings, the variation of the median insulation resistance over the seven year period.

Figures 9 and 10 show respectively, for the pipe and cable coatings, the distributions of insulation resistance measurements as measured initially and after one, two, four and six years. In the case of the coatings buried in 1949, seven-year results are also plotted.

Figure 11 shows the percentages of the coating specimens that showed decreases of 90 percent and 99 percent from the initial insulation resistance values.

Figures 12 and 13 are photographs of typical pipe and cable specimens at the conclusion of the test.

Examination of Coatings Removed in 1951

In April 1951, one specimen of each of seven coatings was removed from box A (natural soil) and box C (soil inoculated with bacteria and waterlogged) for examination of coating deterioration. These coatings had been exposed to soil for 20 months.

Tests for bacteria in the soils from boxes A and C were made using the

TABLE 4—Number of Coating Specimens Buried in Various Soils

MATERIAL	Time Test Was Started	Natural Soil	Inoculated with Fungi			Inoculated with Bacteria		Initially Sterilized
			Moist pH 6.1-6.5	Moist pH 8.0	Water-Logged pH 6.1-6.5	Anaerobic	Aerobic	
Coal Tar Eamel (with Wrapper)	Aug., 1949	4	4	4	4	4	4	4
Asphalt Mastic	Aug., 1949	4	4	4	4	4	4	4
Petroleum Wax (with Wrapper)	Aug., 1949	4	4	4	4	4	4	4
Extruded Polyethylene I	Aug., 1949	4	4	4	4	4	4	4
Extruded Polyethylene II	Aug., 1949	4	4	4	4	4	4	4
Extruded Polyvinyl Chloride	Aug., 1949	4	4	4	4	4	4	4
Reinforced Neoprene	Aug., 1949	4	4	4	4	4	4	4
Coal Tar Enamel (W/O Wrapper)	May, 1950	5	5					
Petroleum Wax (W/O Kraft Paper)	May, 1950	4	4					
Reinforced Neoprene	May, 1950	7	7					
Extruded Neoprene	May, 1950	7	7					
Rubber Neoprene (Network Cable)	May, 1950	5	5					

method of dilution to extinction. The following populations per gram of soil were obtained:

	Box A	Box C
Sulfate reducing	100	10,000
Sulfur oxidizing	1,000	1,000
Thiosulfate oxidizing	1,000	1,000
True Iron	0	0
Iron Thread	0	0
Nitrate reducing	1,000	10

These data indicate a more abundant flora of the sulfate reducing bacteria in the waterlogged soil than in the natural soil. However, the sulfur oxidizing and thiosulfate oxidizing bacteria were present in about the same numbers.

In Table 5 the fungi and actinomycetes isolated and identified from the culture specimens are listed. Some of the fungi were identified to species, others to the genera or the series in which the genera are classed.

The fungi associated with the soil and coatings consisted of at least 10 genera and 19 species. Most of these are soil-inhabiting fungi of rather wide distribution and common occurrence. The genus Gliocladium was the most frequently found form, followed by species of Penicillium and Cephalosporium.

For the laboratory examination, a portion of coating 1 to 1½ inches long was removed from the center of the pipe specimen. The coating was split into two portions, one of which was subjected to microbiological examination. The coating specimens were cleaned of soil and sliced with a razor blade to give sections parallel to the coating surface. The sections were transferred to sterile nutrient media in culture vessels which were incubated for several days and then observed under a microscope for fungus infestation. The results of the examination are described in Appendix A. Figures 14, 15 and 16 are photographs of the exterior surface of the asphalt mastic, petroleum wax and reinforced neoprene coatings, respectively.

Examination of Coatings Removed in 1952

In June 1952, specimens were removed from box B containing soil which had been steam sterilized before being placed in the box in August 1949, and from box H containing natural soil placed in May 1950.

The bacterial populations, per gram of soil, were as follows:

	Box B	Box H
Sulfate reducing	0	1,000
Sulfur oxidizing	100,000	100,000
Thiosulfate oxidizing	1,000	10,000
True Iron	0	0
Iron Thread	1,000	100
Nitrate reducing	100	100

In addition to the bacteria, there were present in the soil or on the coating specimens of these boxes eight genera of fungi. The genera in boxes B and H were similar.

Although the soil of box B was initially sterilized, it now contained numerous bacteria and fungi. The possible sources of origin of these microorganisms were considered to be air-borne spores, tap water for maintaining the normal moisture condition, the coating specimens themselves, and very resistant spores which may have withstood the sterilizing temperatures and germinated later. Within four or five months after
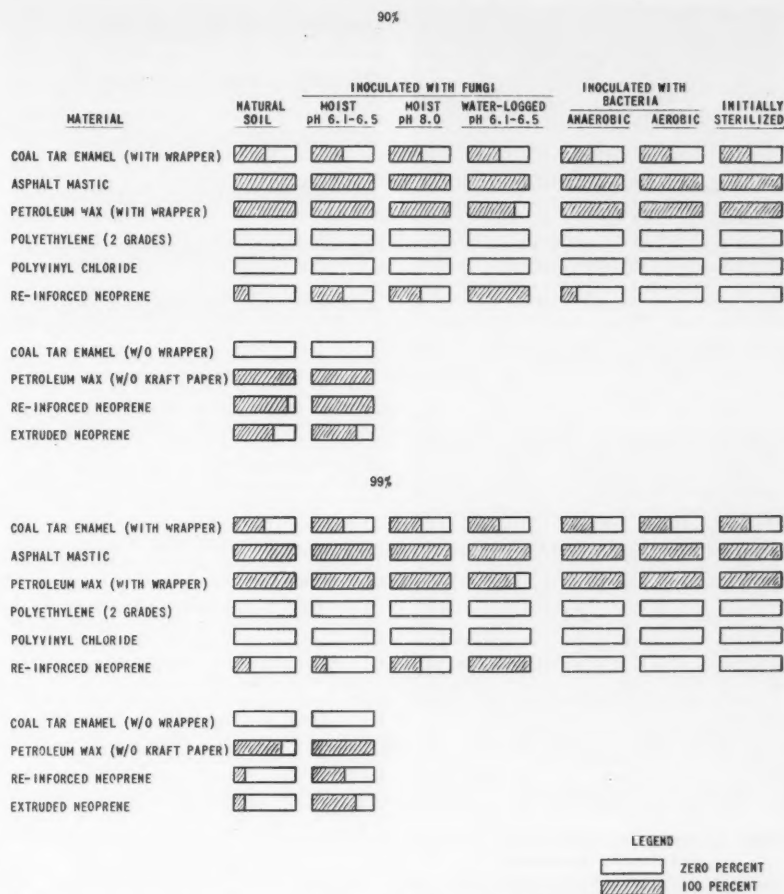
Figure 11—Coating specimens having decreases of 90 percent and 99 percent in insulation resistance.

the start of the experiment, it was noted that active fungus growth had begun on the soil surface. It appears now that the contamination resulted from air-borne spores as well as the tap water applied.

In the laboratory, the coating specimens were cleaned and transferred to culture vessels containing sterile nutrient media. After incubation for several days, observations were made for fungus growth. The results of the examination are shown in Appendix B.

Examination of Coatings at End of Test

Following the last insulation resistance measurements, specimens were removed from box G containing soil which had been inoculated with fungi, adjusted to pH 6.1-6.5, and kept in a waterlogged state. Specimens also were removed from box I, containing natural soil inoculated with fungi. The examination of the specimens was limited to visual observation. No microbiological examinations were made. The results of visual observations made by unaided eye are given in Appendix C.

Discussion of Results—General

In the biological and microbiological fields, numerous variables are present, possibly exceeding the number of variables in metallic corrosion. They include, among other factors, temperature, humidity, aeration, nature and amounts of salts and organic food, pH, and interaction between genera of microorganisms. Obviously, it would have

been impossible to control these factors even within a given box. Thus some variations in results could be expected and were found among replicates exposed to the same soil.

Although the investigation was conducted indoors, the seasonal variation in temperature was sufficient to cause the insulation resistance to vary between relatively high values in the winter to lower values in the summer.

Further sources of variance probably existed in such factors as non-uniformity in dimensions and composition in the coatings.

The coatings in the test were of normal thickness and exposure of several years' duration was necessary in some cases before even tentative conclusions could be reached on their performance.

Discussion of Results—Pipe Coatings

Asphalt mastic began to decrease in insulation resistance soon after burial as shown in Figure 9. These decreases continued until the end of the test. It is difficult to separate the effects of moisture absorption and microbiological deterioration in lowering the insulation resistance. It should be noted, however, that bacterial and fungal colonies were found within the mastic after removal from the soils.

Coal tar enamel specimens with the asbestos wrapper showed more erratic performance than the specimens without the wrapper. The wrapped specimens

showed two distinct patterns of behavior. One group of eleven specimens (at least one in each box) maintained a high resistance in excess of 1,000 megohms per square foot for the duration of the exposure. Conversely, another group of fourteen specimens (at least one in each box) showed sharp decreases in the first six to ten months of exposure and erratic behavior thereafter.

In this connection, it should be remembered that the enamel itself was found to be generally inert to fungus attack. However, fungus growth has been observed in the visual tests on asbestos felt. When coating specimens were removed from the soil boxes, fibers of the asbestos felt wrapper were seen extending through the coal tar enamel, with fungus growth being observed on these fibers. Thus it appears that the asbestos wrapper contained some organic fibers, possibly of animal origin, in addition to the asbestos. Attention is invited to the excellent performance of the coal tar enamel specimens without the wrapper.

Petroleum wax coatings began to decrease in insulation resistance soon after burial and showed the greatest decreases of all materials in the test. Incubation of the specimens removed from exposure showed abundant fungal growth in the outer wax layer and some in the asbestos and inner softer wax layer.

Discussion of Results—Cable Coatings

Extruded polyethylene showed consistently good performance throughout the exposure. Specimens removed from the boxes showed the original smooth

TABLE 5—Fungi Associated With the Soil and Coating Specimens

Coating Specimen	Box A Natural Soil	Box C Waterlogged Soil Inoculated with Anaerobic Bacteria
P-1 Asphalt Mastic	Gliocladium Cephalosporium acremonium Penicillium janthinellum series Penicillium canescens series Spicaria divaricata	Mucor sp. Penicillium ramigena series (two different species) Gliocladium Sporotrichum pruinosum Epicoccum
P-2 Plasticized Coal Tar Enamel	Septocylindrium Cephalosporium curtipes	Sporotrichum pruinosum Cephalosporium curtipes Cephalosporium acremonium
P-3 Petroleum Wax	Trichoderma album Gliocladium	Fusarium nivale Gliocladium
C-1 Polyethylene No. 1	Penicillium chrysogenum series Penicillium implicatum series Trichoderma lignorum Gliocladium Penicillium janthinellum series	Actinomycete Gliocladium
C-1 Polyethylene No. 2	Spicaria Gliocladium Penicillium velutina series Penicillium liliacinum series	Fusarium Actinomycete Gliocladium
C-2 Polyvinyl Chloride	Fusarium sp. Gliocladium	Epicoccum Actinomycete
C-3 Reinforced Neoprene	Gliocladium Actinomycete	Gliocladium Actinomycete

surface and absence of deterioration. There was no apparent difference in performance of the two grades of polyethylene.

Extruded polyvinyl chloride showed consistently good performance. Specimens removed from exposure showed no visible evidence of deterioration. The material appeared to be inert to fungi.

Neoprene coatings, irrespective of manufacture, showed decreases in insulation resistance. After six years, the test of one manufacturer's reinforced neoprene coating showed that ten of the 28 specimens showed decreases of more than 90 percent from the initial resistance, and eight had decreased 99 percent or more.

Another manufacturer's reinforced coating showed gradual changes in insulation resistance for the first five years and sharp decreases thereafter. After six years, five out of 14 specimens showed decreases of 99 percent or more. An extruded neoprene showed good performance for five years before individual specimens began to show sharp decreases. After six years, six out of 14 specimens showed decreases of 99 percent or more.

All neoprene coatings showed at least traces of fungal growth in the body of the coating. As shown by Figure 11, the deterioration occurred most frequently in soils inoculated with aggressive fungi. This result is consistent with conclusions reached by other investigators[5] that fungi cause micropores to develop and ultimately penetrate neoprene. The cotton reinforcing tapes were infested with fungus growth and in some specimens had rotted away in less than two years.

Summary

Previous investigators have demonstrated the microbiological deterioration of natural and synthetic rubbers, cellulose fibers and cellulose-derived resins, and other organic coating materials.

The present investigation concerned coating materials in use, or proposed for use, on underground pipes and cables. Three types of tests were run: (1) visual tests of nutrient inertness and fungistatic effectiveness, (2) physical tests on specimens removed from soil burial, and (3) insulation resistance measurements on coated pipes and cables buried in soil boxes.

The short-time visual tests were found useful for screening materials for more extensive testing in inoculated soils. Only half of 28 coating materials were nutriently inert and only one had fungistatic properties.

Physical tests and inspections showed polyethylene and polyvinyl chloride coating material, exposed to inoculated soil for 12 months, to be immune to deterioration. A neoprene coating became infested with fungi. A tar-impregnated cotton fabric was deteriorated to a marked extent.

Annual insulation resistance measurements on coated pipes and cables buried in soil boxes gave sensitive indication of coating changes. Extent of deterioration was observed on all coatings after six years of exposure. For most coatings, no variation in the performance could be attributed to the type of treatment given the various soils in which the coatings were buried.

The asphalt mastic coating began to decrease in insulation resistance soon

after burial. At the end of the test, the resistance had not reached a stable value. Bacterial and fungal colonies were found within the material after removal from the soils. In some areas softening of the mastic had occurred to such an extent that shallow holes could be dug into the coating by means of a knife blade.

Coal tar coatings without an asbestos wrapper showed good performance while over fifty percent of those with felt wrapper were poor. Coal tar enamel was immune to microbiological attack, but the asbestos wrapper was attacked by fungi in some cases and the insulation resistance of the coating varied erratically.

Petroleum wax coatings showed decreases in insulation resistance throughout the test and the component materials were vulnerable to attack.

Extruded polyethylene and polyvinyl coatings showed no evidence of deterioration. A few pressure sensitive tapes with polyvinyl chloride backing showed questionable performance in the earlier visual tests.

Neoprene coatings showed susceptibility to deterioration in the soil burial tests. The deterioration, as indicated by decreases in insulation resistance, occurred most frequently in soils inoculated with fungi.

Conclusion

For long lasting corrosion protection of underground structures, it is preferable to select coating materials which are inherently inert to microbiological deterioration. From the point of view of deterioration, nutriently inert materials are preferable to those requiring the addition of preservative chemicals. Investigations of deterioration provide data which serve as a basis for selecting stable materials.

References

1. R. L. Starkey and R. M. Wight. Anaerobic Corrosion of Iron in Soil. Final Report of the American Gas Association Iron Corrosion Research Fellowship (1945). American Gas Association, New York 17, N. Y.
2. American Society for Testing Materials, Tentative Methods of Test for Resistance of Textile Materials to Micro-Organisms. D684-45T. ASTM Standards (1946) Part III-A.
3. The Effect of Micro-Organisms on Membranes Proposed for Low-Cost Canal Lining—Interim Report No. B-16, April 17, 1950. Research and Geology Division, Bureau of Reclamation, U. S. Department of the Interior, Denver, Colorado.
4. J. T. Blake and D. W. Kitchin. Effect of Soil Micro-Organisms on Rubber Insulation. Industrial and Engineering Chemistry, 41, No. 8, 1633-1641 (1949).
5. J. T. Blake, D. W. Kitchin and O. S. Pratt. Failures of Rubber Insulation Caused by Soil Micro-Organisms. AIEE Transactions, 69, Part II, 748-54 (1950).
6. J. T. Blake, D. W. Kitchin and O. S. Pratt. The Microbiological Deterioration of Rubber Insulation. AIEE Transactions, 72, Part III, 321-8 (1953).
7. F. E. Kulman. Microbiological Corrosion of Buried Steel Pipe. Corrosion, 9, No. 1, 11-18 (1953).
8. Military Specification MIL-I-631C. Insulation, Electrical, Synthetic-Resin Composition, Non-Rigid, 23 September 1955.
9. American Society of Testing Materials. Standard Methods of Tension Testing of Vulcanized Rubber. D412-41. ASTM Standards (1946) Part III-B.

Appendix A—Examination of Coatings Removed in 1951

In April 1951, coating specimens were removed from box A (natural soil) and box C (soil inoculated with bacteria and waterlogged.). Slices of the coatings were incubated for several days in culture vessels containing sterile nutrient

Figure 12—Coated pipe specimens after seven years' burial.

Figure 13—Coated cable specimens after six to seven years' burial.
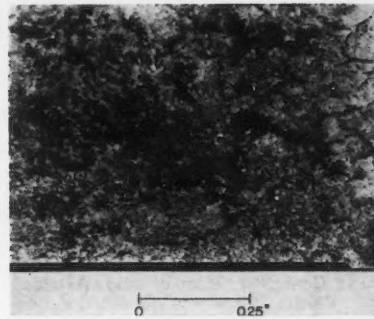
Figure 14—Surface cracking of asphalt mastic after 20 months' burial.

media. The results of microscopic examination were similar for specimens from boxes A and C, and were as follows:

P-1 **Asphalt Mastic:** Asphalt mastic showed minute surface cracks with slight fungus growth occurring from wall to wall within the crack. However, this cracking was apparently superficial and of no serious consequence when considered in relation to the 7/16-inch thickness of the mastic (see Figure 14.)

P-2 **Coal Tar Enamel and Asbestos Felt:** There was no fungus growth on the coal tar enamel. However, it was observed that fibers of the asbestos felt wrapper extended through the coal tar coatings and fungus growth was profuse on these fibers. It appeared that the wrapper contained organic fibers, possibly of animal origin, in addition to the asbestos. Consumption of the organic fibers by microorganisms would allow moisture to penetrate the coating. The observation of fibers traversing the coating would explain the sharp decrease in insulation resistance in some of the coal tar enamel and asbestos felt specimens, in the first year of exposure.

P-3 **Petroleum Wax:** The outer Kraft paper wrapper was rotted, minute cracks had developed in the outer wax coating, and fungus infestation was found on the reinforcing wrapper. The underlying wax layer was slightly affected by the fungi. Figure 15 shows the cracking in the outer wax coating.

C-1 **Polyethylene:** No visible evidence of deterioration was observed on either of the two polyethylene materials. Superficial growth of fungi which was observed did not originate in the material. The materials appeared to be inert.

C-2 **Polyvinyl Chloride:** No visible evidence of deterioration was apparent. Superficial growth of fungi which was observed did not originate in the material. The material appeared to be inert.

C-3 **Reinforced Neoprene Jacket:** The outer cotton fabric had become rotted, leaving a rough surface of neoprene exposed (see Figure 16.) Fungus growth was visible on the surface and on the interior slices of the coating.

Appendix B—Examination of Coatings Removed in 1952

In June 1952, specimens were removed from box B, containing soil which had been initially steam-sterilized, and box

H containing natural soil. Slices of the coatings were incubated for several days in culture vessels containing sterile nutrient media. The results of microscopic examinations on coatings from box B were as follows:

P-1 **Asphalt Mastic:** Pieces of the mastic from the outer, middle and inner zones showed slight growth of bacterial and fungal colonies.

P-2 **Coal Tar Enamel and Asbestos Felt:** There was no growth of fungi on the coal tar enamel. Pieces of the asbestos felt wrapper supported vigorous growth of fungi. Bacterial colonies were found on the felt.

P-3 **Petroleum Wax:** The outer paper wrapper had decomposed and the hard wax layer was cracked into an irregular network of small cracks. During incubation, sections of the outer wax layer and reinforcing wrapper gave rise to fungal growth. Some growth of fungus occurred on the soft inner wax.

C-5 **Reinforced Neoprene Jacket:** The outer fabric had become decomposed, leaving a rough surface of neoprene. Sections from the outer surface of the neoprene showed profuse fungal growth, the central zone slight growth, and the inner layer moderate growth. Tufts of cotton fibers out of the inner fabric layer did not appear to be infested.

The results of examination of coatings from box H were as follows:

P-2A **Coal Tar Enamel:** Slices from the outer, middle and inner zones showed slight growth of fungi and bacteria. This material appeared to be inert. The coal tar enamel coatings in box H did not have a wrapper.

P-3A **Petroleum Wax:** The outer hard wax layer showed a network of small cracks. During incubation, abundant fungal growth was observed in the outer wax layer, and some in the asbestos and inner softer wax layer.

C-4 **Extruded Neoprene Jacket:** The outer surface of the coating became more heavily infested with fungi than the inner fabric layer. Some growth was observed over the neoprene body of the coating but this had its origin in the outer or inner layers.

C-5 **Reinforced Neoprene Jacket:** The outer fabric layer was covered with
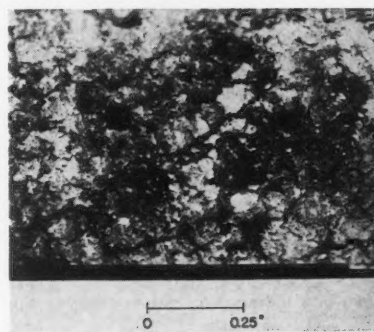
Figure 15—Surface cracking of outer wax layer of reinforced petroleum wax coating.
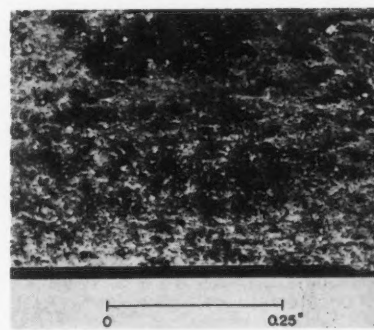
Figure 16—Surface of neoprene coating after cotton fabric had rotted away.

fungus growth, the inner fabric was less infested and the body of the coating was largely free of growth.

C-6 **Network Cable:** The outer surface of the neoprene appeared to be unaffected by the soil exposure. After incubation, only a slight growth was visible on the neoprene; no growth occurred on the rubber.

Appendix C—Examination of Coatings Removed in 1957

Following the completion of the insulation resistance measurements, specimens were removed from box G which had been inoculated with fungi, and box I containing soil also inoculated with fungi. The examinations were made

by unaided eye. Results of the examination for box G were as follows:

P-1 **Asphalt Mastic:** The coating had swollen about $\frac{1}{16}$ inch. Several cracks $\frac{1}{8}$-inch deep were observed. In other areas, softening of the mastic had occurred to such an extent that shallow holes up to $\frac{1}{4}$-inch deep could be dug into the coating by means of a knife blade. The portion of the coating exposed to air showed no softening. There was no corrosion of the pipe.

P-2 **Coal Tar Enamel and Asbestos Felt:** There was no deterioration, deformation, pitting or cracking of either the asbestos felt or the enamel. The bond between the pipe and the enamel was good. There was no corrosion of the pipe.

P-3 **Petroleum Wax:** The outer Kraft paper wrapper had rotted away, and the outer wax coating was penetrated by numerous cracks. The reinforced asbestos wrapper appeared to be slightly brittle. The bond between the pipe and the soft wax layer appeared to be poor and superficial red rust was observed on the iron pipe.

C-1 **Polyethylene:** There was no visible evidence of deterioration, pitting, cracking, change in color or loss of sheen on either of the two polyethylene materials. There was no adhesion of the coating to the lead sheath. The lead sheath had a white discoloration which was easily rubbed off.

C-2 **Polyvinyl Chloride:** No visible deterioration, pitting, cracking, change in color or loss of sheen was apparent. When the coating was removed the lead sheath showed a superficial white discoloration which was easily rubbed off. There was no bond between the sheath and the coating.

C-3 **Reinforced Neoprene Jacket:** The outer cotton fabric had rotted away, leaving an indented pattern on the neoprene surface. The coating had swelled. The bond between the inner cotton fabric and the cable sheath was considered fair. Spots of white discoloration were observed on the lead.

The results of observations on coatings from box I were as follows:

P-2A **Coal Tar Enamel:** This coating, which did not have a wrapper, showed slight indentations, approximately $\frac{1}{32}$ inch deep, caused by sand particles, and shallow corrugations apparently caused by soil pressures. There was no deterioration of the enamel. The bond between the pipe and the enamel was good. There was no corrosion of the pipe.

P-3A **Petroleum Wax:** The outer wax coating was penetrated by numerous cracks. The plastic film reinforcement appeared to be brittle and did not adhere to the asbestos wrapper or to the wax. There was no bond between the pipe and the wax coating and spots of superficial red rust were observed on the iron pipe.

C-4 **Extruded Neoprene Jacket:** The coating had swelled. There was no cracking or pitting, loss of sheen or change of color. The material appeared to be slightly limp. The bond between the pipe and the coating was good and there was no apparent deterioration of the cotton fabric next to the cable sheath.

C-5 **Reinforced Neoprene Jacket:** The outer cotton fabric had rotted away, leaving an indented pattern on the neoprene surface. The coating had swelled. The bond between the inner cotton fabric and the cable sheath was considered fair. Extremely slight pitting of the lead was observed at the edge of the spiral cotton tape.

C-6 **Network Cable:** The overall diameter of the cable had swelled $\frac{1}{16}$ inch. A slight loss of sheen and change of color had occurred on the neoprene jacket. The bond between the conductor and rubber and between the rubber and the jacket was good. The tinned copper conductor was only slightly discolored.

Any discussions of this article not published above will appear in the June, 1958 issue

left margin fragments:

film re-
e brittle
asbestos
ere was
and the
f super-
rved on

et: The
ere was
loss of
or. The
slightly
he pipe
od and
teriora-
next to

et: The
rotted
pattern
e. The
ond be-
ric and
sidered
ting of
e edge

rall di-
swelled
sheen
ccurred
e bond
rubber
nd the
ed cop-
slightly

NACE TECHNICAL COMMITTEE REPORT

Experience With Sweet Oil Well Tubing Coated Internally With Plastic*

A Status Report of Unit Committee T-1C*
On Sweet Oil Well Corrosion

Introduction

IN LATE 1956, NACE Unit Committee T-1C mailed out a questionnaire in an effort to survey the use of plastic coated tubing as a method of combating sweet oil well corrosion. The questionnaire was sent to 16 operators represented on the committee and to 32 non-member companies. Replies were received from 9 committee members and from 6 non-member companies.

From these 15 companies, completed questionnaires were received on 38 fields, located in the Texas and Louisiana Gulf Coast area, in which coated tubing was being used. In addition, one company gave general information on coated tubing used throughout its entire coastal area.

Abstract

A survey was made to determine how operators in the Texas and Louisiana Gulf Coast area used plastic coated tubing as a means of combating sweet oil well corrosion. Reports were received from some 15 companies. Fields containing a total of 2644 sweet oil wells were included in the survey, of which number some 419 were partially or completely equipped with coated tubing for corrosion protection. Of the coated tubing strings, 309 were coated with baked phenolic, 41 with baked modified phenolic-epoxy, 65 with amine cured epoxy, and 4 with other coatings.

Data are reported showing extent to which the various coatings were used with respect to the salt water content for both flowing and gas lift wells. Also included in the report is a discussion of the use of wire line tools, use of caliper surveys, length of service for various coatings, and types of failure experienced.

It was concluded that coated tubing is an effective and economical way to combat corrosion in sweet oil wells. In general this method of corrosion control is most feasible when the wells produce large quantities of water, when abrasive conditions are encountered due to sand and fluid velocity, or when wells are located in marsh and offshore areas where chemical treatment is inconvenient and expensive. **5.4.5**

Summary

1. This survey covered fields containing a total of 2644 sweet oil wells, of which 419, or 15.8 percent, were partially or completely equipped with coated tubing for corrosion protection. Of the coated tubing strings, 309 were coated with baked phenolic, 41 with baked modified phenolic-epoxy, 65 with amine cured epoxy, and 4 with other coatings. One operator stated that some of his later wells were coated with the combination baked phenolic-modified phenolic-epoxy overlay although they were reported as being coated with phenolic. Of the coated tubing strings reported, the majority were installed in flowing wells with the larger percent of these being in pipe line oil wells and with wells making over 50 percent salt water in second place. Gas lift wells making over 50 percent salt water occupy the fourth position as to number of coated strings installed.

2. The length of service for the majority of coated tubing strings reported was fairly short except for those coated with baked phenolic. Several baked phenolic strings were reported with

service of over 5 years, with the longest service as being 10 years. The longest reported service for baked modified phenolic-epoxy was 2 years and for amine cured epoxy 2½ years.

3. From the lack of failures reported, it is evident that coated tubing is being used successfully as a method of combating corrosion. Only six strings were reported as being partially or completely removed due to failure of the coating. Two of these strings were coated with chlorinated rubber, a material which is no longer being used. The failure of two strings coated with a modified phenolic was also reported, but the tubing is being chemically treated rather than being removed.

4. Wire line work is being performed in coated tubing by six operators. Usage ranged from testing in nipples to considerable routine operations. Minor to no damage to coatings was reported ex-

* Joy T. Payton, The Texas Co., Research and Technical Dept., Bellaire, Texas, chairman.

cept for one string which was reported as a failure due partly to wire line work.

5. Caliper surveys were run by five operators, ranging from limited checks to routine surveys. No damage attributable to the caliper surveys was reported.

6. Only three operators reported that they had set any specific limitations on the use of coated tubing. Temperature limitations varied from 200 F to 300 F for phenolic, 200 F to 250 F for modified phenolic-epoxy, and 140 F for amine cured epoxy. One operator does not favor the use of coated tubing in wells where considerable wire line work will be performed.

7. All operators reported that past history, either their own or that of others, was the criterion for use of coated tubing. Also, a number of operators used coated tubing for preventive insurance, especially in the Louisiana Gulf Coast area and on offshore operations.

8. According to reports received, the use of coated tubing is generally considered economically justified. Phenolic coatings have the longest history of service, but the modified phenolic-epoxy is being favored by a number of operators as having better caustic mud and abrasion resistance.

Discussion

This survey has encompassed only a small portion of the coated tubing being used to combat corrosion in sweet oil wells, but it is felt that a representative cross section of experience has been obtained that can be used as a barometer for the industry. When it is considered that coated tubing has been installed in 15.8 percent of all wells reported, regardless of their corrosiveness, it is evident that coatings have been accepted as a reliable corrosion preventive method.

Approximately two-thirds of the coated tubing strings reported in this survey are installed in the Louisiana Gulf Coast area, and the majority of these strings are installed in flowing pipe line oil wells. Sixty percent of the coated tubing installed in the Texas Gulf Coast area is in wells producing over 50 percent salt water.

Table 1 gives the division of coated tubing strings reported as presently being used for sweet oil well corrosion as to producing method, percent of salt water produced, and type of coating being used:

Length of Service

Successful service has been obtained by coated tubing in sweet oil well corrosive environment for a period of more than 10 years. This coating (baked phenolic) was inspected during a workover after approximately eight years of serv-

ice and found to be in very good condition. Out of the 38 fields reported as using coated tubing, 10, or 26.3 percent, were reported as having baked phenolic coating in service for over five years. The baked modified phenolic-epoxy and amine cured epoxy coatings are relatively new as internal tubing coatings, but successful service has been obtained from these coatings during the time they have been available, or from approximately 2 to 2½ years.

The various methods being used to determine the condition of coating in the tubing are visual inspection during workovers or the pulling of tubing for this specific purpose, calipers, iron content of produced water, and the final criterion of relative time that coated tubing will last in a well compared to noncoated tubing. The exact condition of a number of coated tubing strings reported was unknown, mainly because they had not been installed for sufficient time to warrant any type of inspection.

Failures

This survey indicates that internal coatings in tubing are doing an excellent job of corrosion prevention, inasmuch as only six strings were reported as being partially or completely removed due to failure of coating. When these failures are broken down further, the success of internal coatings looks even better. One phenolic coated string was removed after two years because of damage by sand production and wire line work in cutting paraffin. Excessive scale build-up caused the removal of another phenolic coated string after about three years. Four joints of phenolic coated tubing were replaced in a string of 100 joints after 7½ years of service. Seven joints of phenolic coated tubing were replaced in a string due to sand production after two years of service. The other two failures were chlorinated rubber coated tubing which is no longer being used.

Failure of two strings of modified phenolic coated tubing, caused by production fluids penetrating and removing coating after 28 and 44 months of service, were reported. These tubing strings were not removed but presently are being chemically treated. One large user of coated tubing reported he had not replaced any tubing strings due to failure but had chemically treated all wells that required wire line work on the assumption that the coating might be damaged.

Wire Line Work

The use of wire line tools in coated tubing generally is not practiced except in cases where it is made necessary by changing or unforeseen conditions. Six operators reported having used wire line tools in coated pipe; their experience

varied from complete failure to little or no damage.

The main type of wire line work being performed is cutting of paraffin. Three operators reported doing a considerable amount of routine paraffin cutting in coated pipe, of whom two indicated little or no damage to the coating except the one failure. The third operator indicated that he had not determined the extent of damage to the coating. One operator stated that he immediately assumed damage to coating when paraffin scrapers were used and started chemical treatment accordingly.

Wire line work is being performed in both baked phenolic and modified phenolic-epoxy coated tubing, but the baked modified phenolic-epoxy is reported as being favored due to its greater resistance to abrasion.

Calipers

Several operators reported that they were reluctant to use caliper surveys to determine the condition of coated tubing for fear of damaging the coating with the caliper. Five operators indicated that they had used calipers in coated tubing, and none reported damage to the coating attributable to running the caliper surveys. Two of these operators reported that calipers were frequently run in coated tubing strings with no damage. The other operators reported only limited use of calipers with no damage reported except for one field where the possibility of damage has not been determined. The experience of one operator on calipering coatings is limited to coated gas lift mandrels in tubing strings that are calipered. This operator coats all gas lift mandrels installed and damage that can be attributed directly to calipering has not been found on any mandrel inspected to date.

Limitations

The majority of the operators participating in this survey do not seem particularly concerned about setting limits of temperature, depth, abrasiveness, etc. A possible explanation for this is that the sweet oil well conditions in which coatings are presently being used fall so far below applicators' recommended limits that there is no need as yet to consider the problem.

Three operators set temperature limits of 200 F-300 F for baked phenolic, 200 F-250 F for baked modified phenolic-epoxy, and 140 F for amine cured epoxy. One operator set a limit of 200 F for baked phenolic coating when caustic mud is used and stated a preference for baked modified phenolic-epoxy coating for hot caustic and abrasive conditions. The limitation of not using coated tubing in wells where excessive wire line work will be done was set by

TABLE 1—Distribution of Types of Coated Tubing

| PLASTIC | PIPE LINE OIL | | SALT WATER | | | | | |
| | | | 0-30% | | 30-50% | | Over 50% | |
	Flowing	Gas Lift	Flowing	Gas Lift	Flowing	Gas Lift	Flowing	Gas Lift
Baked Phenolic	161	4	35	6	21	3	42	34
Baked Phenolic-Epoxy	6	2	11	0	2	0	11	9
Amine Cured Epoxy	10	1	15	1	8	0	16	14
Others	0	0	1	0	0	1	0	0
Total Coated Tubing	177	7	62	7	31	4	69	57

one operator. Another operator said that economics was the only limiting factor regarded for his use of coatings.

Criteria

The criteria used by all operators for determining the need for coated tubing is past history, either their own or that of others, of corrosiveness in the field and service of coating under similar conditions. Also, coated tubing is used by a number of operators for preventive insurance. This is especially true of wells in marsh and offshore locations where failures can be extremely dangerous and costly.

General Evaluation

The operators participating in this survey generally consider that coated tubing is a good method of combating sweet oil well corrosion. This evaluation of coating by a large number of the companies is based on successful experience with coatings in severe corrosion environment. Table 2 gives a breakdown on a percentage basis of the suc-

TABLE 2—Years of Successful Service of Plastics

	YEARS SUCCESSFUL SERVICE				
	0-1	1-2	2-3	3-5	5+
Percent by Fields..................	21.0	42.2	7.9	2.6	26.3
Percent by Companies.............	25.0	8.3	16.7	0.0	50.0

cessful experience with coated tubing among the fields and companies participating in this survey.

Baked phenolic coatings have been available longer and therefore have been, to a great extent, the yardstick in evaluating this method of combating corrosive conditions. The baked modified phenolic-epoxy coating is considered by a number of operators as an improvement over the phenolic, especially in abrasion resistance and in resistance to caustic muds. Use of amine cured epoxy coating was recommended by one operator for low pressure, shallow oil wells and flow lines, but the baked coat-

ings are preferred for all other types of wells.

The economics of coated tubing will have to be considered on the corrosive and/or other conditions in each field, but, in general, the following conditions are best suited for economical use of coated tubing:

1. Wells which produce large quantities of water.

2. Wells in which abrasive conditions are encountered due to sand and fluid velocity.

3. In marsh and offshore areas where workover costs are expensive and it is inconvenient and expensive to use chemical treatment.

Effects of Cold Working on Corrosion
Of High Purity Aluminum in Water at High Temperatures*

By M. J. LAVIGNE

Introduction

IN A PREVIOUS publication,[1] the author reported that high purity aluminum[(1)] corrodes intergranularly in distilled water of pH 6.0-7.0, at 150 C and even at 100 C. Microexamination of the corroded specimens indicated that the attack took place preferentially at the boundaries of contiguous grains with different orientations. Corrosion tests carried out in distilled water at 150 C on some high purity aluminum specimens indicated that sometimes the attack did not occur in unannealed metal, but always occurred when it was annealed. This seemed to indicate that the occurrence of intergranular corrosion in the aluminum was dependent on the metallurgical condition of the material. For this reason the present paper describes the corrosion resistance of high purity aluminum, both cold-worked and cold-worked-and-annealed.

Experimental Techniques

Materials

The high purity aluminum used for this investigation was obtained in ingot form from the Aluminum Company of Canada Limited. At the Mines Branch of the Department of Mines and Technical Surveys, Ottawa, the ingot was remelted, cast into a billet, and rolled on an 18" mill to 0.50" and subsequently to 0.25" thick sheets. New rolls were used to avoid contamination. The material was then annealed for one hour at 500 C and rolled to thicknesses which would allow subsequent reductions in thickness of 90, 80, 70, 60, 50, 40, 30, 20, 10 and 5 percent, ending with a final thickness of 0.040". At this stage the sheets were given a final annealing of two hours at 500 C before the last series of passes to reduce them to 0.040" sheets. The final rolling was carried out as follows: material below 0.057" was reduced by 0.001" passes, from 0.057" to 0.100", by 0.003" passes; from 0.100" to 0.134", by 0.005" passes; and from 0.133" to 0.509", by 0.010" passes. Varsol was used as a lubricant so that there would be no pick up from work to roll or vice-versa.

The rolled material was analyzed and found to contain 0.0068 percent Si and 0.0028 percent Fe. The copper content was not determined but it is estimated to be not more than 0.002 percent.

Heat Treatment

For comparison with cold-worked material some of the sheets reduced to various percentages were annealed at a temperature for a time long enough for complete recrystallization. The suitable annealing temperature and soaking time were determined by following the changes in hardness with time at various

About the Author

M. J. LAVIGNE was formerly in charge of Nuclear Metallurgy Section of the Department of Mines and Technical Surveys seconded to Atomic Energy of Canada Limited, Chalk River, Ontario, and is now head of Metallurgy Section, Atomic Energy Division of Canadian Westinghouse, Hamilton, Ontario. From Laval University, Quebec, he received a BASc in metallurgy in 1943, and a doctorate degree in metallurgy in 1954. He is a professional engineer of the Province of Ontario (1943) and is a member of ASM and AIME.

temperatures. Annealing for one hour at 400 C appeared most satisfactory to produce complete recrystallization. The hardness of the cold-worked material varied from 22 DPH for the 5 percent to 33 DPH for the 90 percent worked aluminum, as determined with the Erb & Gray micro-hardness testing machine using a 50 gram-load. After 25 minutes at 400 C, the hardness of the materials decreased to a constant value of about 17 DPH.

Corrosion Testing

After degreasing and drying in a desiccator, five samples (1" x 1" x 0.040") of each of the cold-worked and cold-worked-and-annealed aluminum samples were submitted to corrosion in distilled water, of pH near neutral, at 100 C. The corrosion test was carried
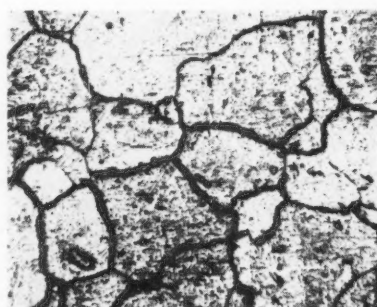
Abstract

The effects of cold-working, and of cold-working and annealing to complete recrystallization, on the corrosion resistance of high purity aluminum in water at 100, 150 and 200 C have been determined.

In distilled water at 100 C, high purity aluminum cold-worked 5 to 50 percent inclusive and all the recrystallized aluminum samples corrode intergranularly, but materials cold-worked 60 percent and over are immune to this type of attack.

At 150 C and 200 C the 60 percent and the 70 percent cold-worked materials corrode intergranularly while the 80 percent and the 90 percent cold-worked corrode generally. The attack on the latter materials appears also to be selective, as some grains corrode preferentially to others.   3.7.3

out in two large pyrex beakers with pyrex condensers. Samples were removed periodically from the containers for microexamination and determination of their corrosion rates. Defilming was done in the phosphoric-chromic acid solution according to the ASTM-B-137-45 Specification.

New samples of the materials (¾" x 2" x 0.040"), which were not attacked intergranularly after a six-week immersion in water at 100 C, were submitted to test in a stainless steel autoclave at 150 C and 200 C. The samples were supported by a Teflon spider.

Results

The aluminum samples cold-worked up to 50 percent inclusive showed intergranular corrosion after one week of testing in distilled water at 100 C, but the samples cold-worked from 60 to 90 percent after five months of testing still showed no signs of intergranular corrosion. Figure 1 shows the surface of a 5 percent cold-worked sample after testing in distilled water at 100 C for 51 days and defilming. Figure 2 is a photomicrograph of the cross-section of a 20 percent cold-worked sample tested at 100 C for 26 days.

Figure 3 shows a mechanically polished cross-section of a 90 percent cold-worked sample tested at 100 C for 53 days.

Figure 1—High purity aluminum (cold worked 5 percent) after testing in distilled water for 51 days at 100 C. Original magnification, 64X; actual magnification after reduction for engraving purposes, 35X.
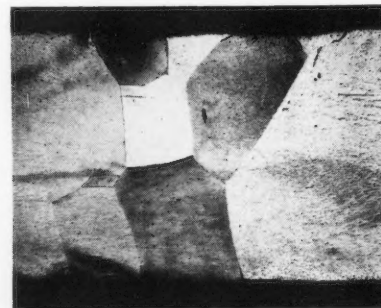
Figure 2—High purity aluminum (cold worked 20 percent) after testing in distilled water for 26 days at 100 C. Sample was electropolished and anodized; cross-section is shown under polarized light. Original magnification, 40X; actual magnification after reduction for engraving purposes, 22X.
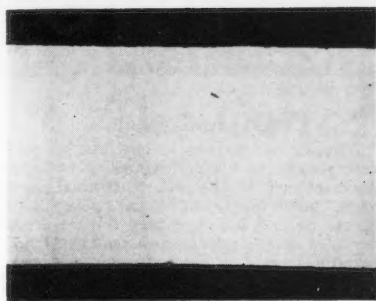
Figure 3—High purity aluminum (cold worked 90 percent) after testing in distilled water for 53 days at 100 C. Cross-section shown here was polished. Original magnification, 40X; actual magnification after reduction for engraving purposes, 23X.

Figure 5—High purity aluminum (cold worked 90 percent) after testing in distilled water for 53 days at 100 C. Phase contrast is shown. Original magnification, 200X; actual magnification after reduction for engraving purposes, 110X.
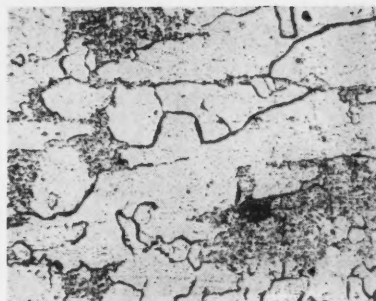
Figure 6—High purity aluminum (cold worked 90 percent) after testing in distilled water for 124 days at 100 C. Specimen had been annealed at 400 C for one hour. Original magnification, 64X; actual magnification after reduction for engraving purposes, 35X.

Figure 4—High purity aluminum (cold worked 90 percent) after testing in distilled water for 53 days at 100 C. Cross section was electropolished and is shown here under polarized light. Original magnification, 40X; actual magnification after reduction for engraving purposes, 23X.

TABLE 1—Effects of Cold-Working on the Corrosion Resistance of High Purity Aluminum in Distilled Water

Condition of Material, Percent Cold-Worked	CORROSION RATES, INCH PENETRATION PER MONTH			
	110 C*	150 C**		200 C**
	After 1272 Hours	After 72 Hours	After 768 Hours	After 48 Hours
60	0.00003^G	0.0007^I	0.0033^I	0.0533^I
70	0.00003^G	0.0008^I	0.0031^I	0.0448^I
80	0.00005^G	0.0029$^{G\&S}$	0.0044$^{G\&S}$	0.0523$^{G\&S}$
90	0.00004^G	0.0053$^{G\&S}$	0.0041$^{G\&S}$	0.0440$^{G\&S}$

* Average of 5 specimens.
** Average of 2 specimens.
Note: Code to letters is as follows. ^{G} General attack; ^{I} Intergranular attack; ^{S} Selective attack.

There is no crevice on the two large surfaces of the specimen, except some small surface defects which probably were produced by the rolling. Figure 4 shows the banded structure of the same specimen under polarized light and Figure 5 indicates that there is no attack at the boundary of the two bands shown by phase contrast.

Annealing at 400 C for one hour somewhat sensitized all the cold-worked materials: all corroded intergranularly in two days. Figure 6 is a photomicrograph of a 90 percent cold-worked and annealed specimen as corroded.

Corrosion rates were determined for all the cold-worked and cold-worked-and-annealed specimens tested at 100 C but only the corrosion rates of specimens which did not corrode intergranularly are reported in Table 1.

Corrosion tests carried out in distilled water at 150 C for 72 hours on specimens of the 60, 70, 80 and 90 percent cold-worked materials indicated that a few grain boundaries of the 60 percent and 70 percent samples were attacked, while the 80 percent and 90 percent reduced materials corroded generally. It should be mentioned that the attack on the latter materials appeared to be selective as some grains corroded preferentially to the others.

A one-week test carried out on the same materials at 150 C intensified the different types of attack and confirmed the results obtained in the 72-hour test. Although it is not technically sound to compare corrosion rates of samples which corroded in different ways, it is interesting to note in Table 1 that at 150 C the corrosion rates (based on loss in weight) for the 60 and 70 percent cold-worked materials is less than that of the 80 percent and 90 percent cold-worked materials.

Corrosion tests carried out in water at 200 C for 48 hours on specimens of the same materials, indicated that the intergranular corrosion noticed on the 60 and 70 percent cold-worked samples was greatly intensified by an increase of 50 Centigrade degrees in the testing temperature and that the selective attack was greatly increased on the other materials.

Figure 7 shows the condition of one of each of the materials after the test. It can be seen that the 60 percent and 70 percent cold-worked metal suffered severe intergranular attack while the 80 and 90 percent corroded generally. The attack on the latter materials was also selective, as some grains corroded preferentially to others. The 80 percent cold-worked material corroded intergranularly only at a few grain boundaries.

Figure 8 represents the transverse cross-section of an 80 percent cold-worked sample after corrosion at 200 C for 48 hours. The corrosion rates of the specimens tested at 200 C for 48 hours are given in Table 1.

Discussion of Results

It appears from the results of tests at 100 C and 150 C that cold-working does not significantly affect the general corrosion rate of high purity aluminum. Cold-working 60 percent and over eliminates intergranular corrosion in the high purity aluminum exposed to distilled water at 100 C, retards it at 150 C, but does not render the material immune to this type of attack at higher temperatures. Annealing at a temperature and for a length of time suitable for complete recrystallization, such as 400 C for one hour, sensitizes the material and renders it susceptible to inter-

granular corrosion in distilled water at 100 C.

It could be argued that the higher temperature of testing could result in some recrystallization and the premature failure of the material. However, hardness tests made on 80 percent cold-worked samples before and after corrosion testing at 200 C for 48 hours indicated that complete recrystallization did not occur under the testing condition. The hardness of the material remained about the same (it dropped only from 31 to 28 DPH). Metallographic examination of the cold-worked metal before and after corrosion testing also showed that there was no detectable change in grain size. The aluminum used was not of "super-purity," having only a 99.98 percent maximum aluminum content. It is improbable, therefore, that the annealing at 200 C during testing changed significantly the metallurgical condition of the material and was responsible for the early failure of the material by intergranular attack. The results are also in accordance with the findings of B. Nauton[2] and H. Chossat et al[3] on the recrystallization temperatures of high purity aluminum grades.

Some of the grains in the 70 percent cold-worked material, revealed by intergranular corrosion and shown in Figure 7, appear to be unduly large. Microstructure studies of such grains under polarized light after oxidizing, and also etch pit figure studies, seem to indicate that the large grains are clusters of grains with about the same orientation.

J. Draley[4] proposes the hydrogen mechanism to explain the corrosion behavior of aluminum in water. He suggests that some of the hydrogen atoms produced in the corrosion reaction diffuse into the metal structure, mostly at structural defects, and, upon combination to form molecular hydrogen, pro-
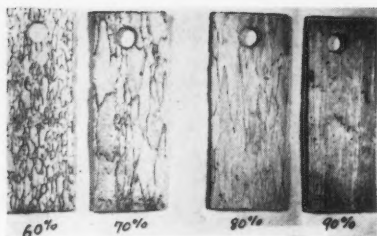
Figure 7—High purity aluminum (cold worked 60 to 90 percent) after testing in distilled water for 48 hours at 200 C. ½X.

Figure 8—Cross-section of sample of high purity aluminum (cold worked 80 percent) after testing in distilled water for 48 hours at 200 C.

duce pressure pockets in small voids in the metal; as the weak metal yields, these pressure pockets cause the formation of blisters which subsequently rupture and let the water in. Blisters were not observed on the high purity aluminum samples used in this investigation but the edges of the grains were lifted from the surface of the metal. Jean Duflot,[5] in his study on the supersaturation of iron with cathodic hydrogen, has also observed the formation of blisters and inter- and intra-crystalline internal defects.

It appears reasonable, therefore, to think that the better resistance of the cold-worked material to intergranular attack is due to the lower degree of misfit between contiguous grains. The diffusion of atomic hydrogen at grain boundaries is then somewhat retarded. However, heavily cold-worked material is subject to selective attack, some grains corroding preferentially to others. This preferential etching on a microscopic or sub-microscopic scale may be due to the fact that the orientation given to these grains by cold-working is not uniformly suitable for the growth of a dense and protective film.

Conclusions

The results of the tests have indicated that metallurgical factors greatly influence the corrosion resistance of high purity aluminum in distilled water. Cold-worked aluminum up to 50 percent, and all completely recrystallized aluminum, corrode intergranularly in distilled water at 100 C, while aluminum cold-worked over 60 percent is immune to this type of attack. At 150 C and higher temperatures, cold-worked aluminum is susceptible to intergranular corrosion and also to selective attack.

References

1. M. J. Lavigne. Intergranular Corrosion of High Purity Aluminum. *Metal Progress,* **64,** No. 3, 84-86 (1953) Sept.
2. B. Nauton. Etude de la recristallisation de trois aluminiums de haute pureté á l'aide de leurs propriétés mecaniques. *Revue de Metallurgie,* **49,** 453-457 (1952).
3. H. Chossat, M. Monflard, P. Lacombe and G. Chaudron. *Comptes Rendus* (Acad. Sci., Paris), 227, 342 (1948).
4. J. Draley and W. E. Ruther. Corrosion Resistance Aluminum Above 200 C. Argonne Nat. Lab., ANL-5430 (1955).
5. J. Duflot. Contribution á l'étude de la sursaturation du fer en hydrogene cathodique, No. 265, Service de Documentation et d'Information Technique de l'Aéronautique, Paris, France, No. 265 (1952).

Methods for Increasing
The Corrosion Resistance of Metal Alloys*

By N. D. TOMASHOV

Introduction

THE THEORY of corrosion and metal protection is as much an independent science as is theoretical metallurgy. Both of these fields form part of physical chemistry, but now, owing to their extensive independent development and special practical value they have assumed the full status of separate branches of knowledge.

The science of corrosion and metal protection deals with the physico-chemical destruction of metal and alloy surfaces, and aims at establishing laws underlying the destruction of metallic structures (lattices) under external influence. In the practical field, the objective of this science is to develop effective scientific methods of protecting metals and metal constructions under various conditions.

The first attempt to approach scientifically the dissolution of metals in electrolytes was made in the first half of the eighteenth century.[1] Since then the theory of metal destruction in various media has developed continually in accordance with practical requirements. Among the many scientists helping to develop the science of corrosion and metal protection were M. Faraday, De La Rive, Palmaer, W. Walker, W. Whitney, A. Cushman, W. Tilden, M. Zentnerszwer, A. Thill, G. Tamman, U. Evans, T. Hoar, T. Hudson, R. Mears, F. Speller, G. Masing, W. Vernon, C. Wagner, H. Uhlig, I. Denison, R. Brown and others.[2-14] The investigations by these authors form the keystone of contemporary views on the nature of physico-chemical metal destruction. Of considerable value for the development of corrosion theory were the works of such Soviet Union scientists as Kistiakovsky,[15] Izgarishev,[16-18] Frumkin,[19-20] Akimov[21-22] and their numerous followers and disciples.[23-48]

It is unnecessary to repeat here the well known figures on the enormous damage caused by corrosion and emphasize the importance of corrosion control. What should be said, perhaps, is that many new and important branches of corrosion mitigation could never have been developed without the efforts of metallurgists and corrosion engineers, creators of special corrosion resistant alloys.

Metal corrosion is determined not only by the alloy composition and the state of its structure (i.e., by internal factors), but also by external factors (i.e., composition of the corrosive medium, velocity of its movement, its temperature, etc.) In this paper, however, attention will be directed primarily to the influence of changes in alloy structure or composition on the rate of corrosion

About the Author

N. D. TOMASHOV is Professor, Doctor and Scientific Director of the Corrosion Department in the Institute of Physical Chemistry of the USSR Academy of Sciences, Moscow. During his more than 25 years in scientific work his main interests have been in the field of corrosion and metal protection.

under constant external conditions. The paper will be further restricted to the most widespread case of corrosion in electrolytes — electrochemical metal corrosion.

Local Cells in Alloy Corrosion

The corrosion of metals and alloys in electrolytes, as viewed in the fundamental works on corrosion, is electrochemical in nature and may be described from the general principles of electrochemical kinetics.[3, 20, 21, 24, 25]

Today is can be considered as established that the functioning of local corrosive micro- and macro-cells on the surface of a dissolving metal, is not the primary cause of corrosion. The primary cause of corrosion is the thermodynamic instability of most metals and alloys in atmospheric conditions and in most water solutions.

The process of corrosion may develop in different ways. Sometimes the prevalent process is electrochemical corrosion without the sharp differentiation of cathodic and anodic phenomena in separate areas (homogeneous electrochemical corrosion). Nor should the possibility be excluded of corrosion developing through direct interaction between the metal surface and the surrounding liquid or gaseous medium without any separate anode or cathode stages (chemical corrosion). But in the case of an electro-conductive corrosive medium and with an electrochemically heterogenous metal surface, more probable and prevalent is the process of heterogenous electrochemical corrosion.[24, 25]

Analysis of most practical cases of corrosion proves beyond doubt that the principal corrosive effect is caused by a process accompanied by clear differentiation of cathodic and anodic

Abstract

A detailed investigation is made of the general laws governing the increase of corrosion resistance of metallic systems by means of alloying. The role of local cells in alloy corrosion is considered briefly. Some attention is given also to the control characteristics of corrosion processes. Other topics discussed include structural heterogeneity and metal alloy corrosion resistance, conditions for development of metal passivity, and methods of increasing metal and alloy corrosion resistance.

It was found that with corrosion controlled by oxygen diffusion, cathodic inclusions do not notably accelerate corrosion. When it is possible to establish prevalent anodic control, cathodic inclusions may promote passivation and consesuently considerably reduce the rate of corrosion.

The degree of passivity may be regarded as a value equivalent to the degree of anodic control effected in a given process. When this is taken into account it is possible to propose a new method for calculating the degree of passivity of different metals. Approximate calculation of the passivity of metals in aerated 0.5N NaCl solutions gave the following order of reduction of degree of passivity: Ti, Al, Cr, Be, Mo, Mg, Ni, Co, Fe, Mn, Zn, Cd, Sn, Pb and Cu.

The possibility of increasing alloy corrosion resistance by additional cathodic alloying was interpreted by analyzing the polarization diagram. The possibility of increasing the corrosion resistance of readily passivated metallic systems was tested experimentally.   3.7.2

phenomena in separate areas, and therefore must be associated with the action of micro- or macro-corrosive couples. The irregular destruction of metallic alloy surfaces usually visible during corrosion in electrolytes, is connected with the activity of macro corrosive couples. This latter action is more probable as there is more low ohmic resistance, and also a possibility of cathodic impurities continually gathering on the surface during the course of corrosion.[21, 24, 25]

It is clear that there is good reason to associate insufficient corrosion resistance with greater efficiency of corrosive electrochemical couples on the alloy surface. Thus the question as to why some alloys are more resistant than others under the given circumstances, is to a considerable extent synonymous with the question of why corrosive couples are more active on some alloys than on others.

With the help of the homogenous electrochemical corrosion theory given in the works of C. Wagner and W. Traud, Frumkin, Kolotirkin, Durdin, Scorcelletti, Shultin et al,[4, 19, 20, 26-31] it is possible to make a consistent analysis of the ways of increasing corrosion resistance of alloys, arriving at conclusions analogous to those derived in the present work. The authors prefer to analyze the problem from the standpoint of the heterogenous electrochemical theory, owing to its more general nature and the greater probability of its being applied to the explanation of corrosion in alloys and technical metals.

In the present paper the general prob-
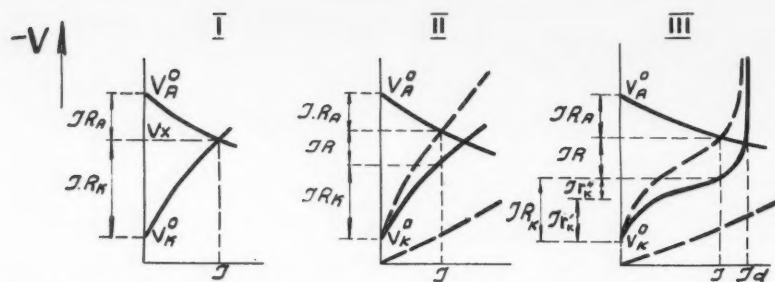
Figure 1—Determination of corrosion control nature from analysis of polarizing diagrams. I—Ohmic resistance is low, relationship R_A: R_K determined from relationship IR_A: IR_K. II—General case. Relationship R_A: R_K: R determined from relationship IR_A: IR_K: IR. III—more detailed characteristic of cathode control. Relationship R_A: r'_K: r''_K: R determined from relationship IR_A: IR_K: IR taking into account the equations

$$R_k = r'_k + r''_k \text{ and } \frac{r'_k}{r''_k} = \frac{I_d - I}{I}$$

where r'_k — is the inhibition caused by the cathode reaction; r''_k — the inhibition caused by depolarizer diffusion; I — corrosion current; I_d — maximum diffusion current. (For detailed calculation see Reference 33).
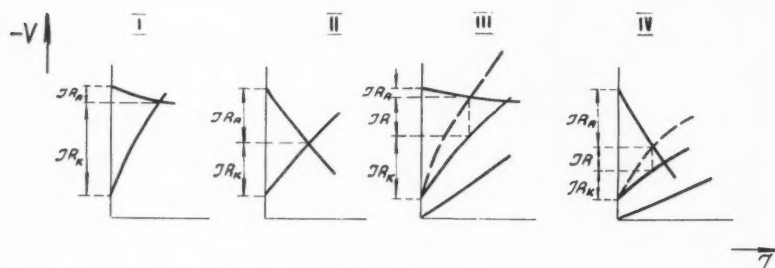
Figure 2—Typical cases of corrosion control for different conditions of corrosion: I—active corrosion in electrolytes; II—corrosion in passive state; III—corrosion at the expense of macrocouples (soil corrosion); IV—corrosion under a thin film of moisture (atmospheric corrosion).

TABLE 1—Assorted Corrosion Data for Metals in An Aerated 0.5N NaCl Solution

Metal*	Standard Potential,** V_n	Corrosion Potential,** V_x	Passivity Factor,*** P	KpH**** O N
Cu	+0.337	+0.058	0.0	
Pb	−0.126	−0.312	0.0	V 8
Sn	−0.136	−0.205	0.0	V 8.5
Mo	−0.20	+0.105	0.49	V
Ni	−0.250	−0.007	0.37	/
Co	−0.277	−0.144	0.20	/
Cd	−0.403	−0.531	0.0	/
Fe	−0.440	−0.30	0.18	V 14
Cr	−0.74	−0.109	0.74	/
Zn	−0.763	−0.782	0.023	V 12
Mn	−1.18	−1.00	0.13	<
Ti	−1.63	+0.181	0.82	V
Al	−1.66	−0.571	0.82	V 6.5
Be	−1.85	−0.764	0.73	/
Mg	−2.37	−0.401	0.47	/

* The degree of passivity falls in the following order: Ti-Al-Cr-Be-Mo-Mg-Ni-Co-Fe-Mn-Zn-Cd-Sn-Pb-Cu.
** The potentials are given in relation to a normal hydrogen electrode.
*** Passivity factor P equals the ratio between anodic and cathodic inhibition at the action of the given corrosive cell. The greater the passivity factor, the more perfect the degree of passivity of the given metal during its corrosion in a NaCl solution. For details on calculation of degree of passivity see references 24 and 37.
**** KpH represents dependance of corrosion on solution pH for a number of metals in an aerated 0.5 N NaCl solution. The symbol "/" shows the reduction of the given metal's corrosion rated with pH increasing from 0 to 14, symbol "V" shows the corrosion minimum at the pH value given beside it.

lems of the theory of electrochemical corrosion will not be examined inasmuch as this has been thoroughly done in a number of works.[2-8, 20, 22, 24, 25, 32] Instead, emphasis will be placed on the corrosion controlling factor and the influence of cathode inclusions on metal corrosion resistance. This is a matter which is important for deriving the main laws governing metal alloy corrosion resistance.

The Corrosion Controlling Factor

The kinetics of corrosion-cell action which determine the rate of electro-chemical corrosion depend on the extent of inhibition of the general corrosive process at its three main stages: the cathodic and anodic processes and the transport of charges in the metal and the electrolyte. It is easy to give a relative estimate of the values of electro-chemical corrosion inhibition at these main stages, and also at the more elementary stages into which the latter may be subdivided, all of them being characterized by the same units of measurement (ohms). The relationship between the values of inhibition at different stages, usually measured by the voltage

drop at the given stage, is the most important characteristic of the corrosive process for the given conditions of corrosion and may be called *the control characteristic of the given corrosive process.*

The building and analysis of polarizing diagrams has served to elaborate quantitative methods of evaluating corrosion control.[3, 24, 25, 33] Figure 1 shows some simple examples of such graphic evaluations. In those cases of corrosion where ohmic inhibition is negligible, (Figure 1, I) the relationship between cathodic and anodic control is determined in respect to the changes of potentials at anodic and cathodic polarization. If need be, the relationship also may be calculated between anodic, cathodic and ohmic inhibition (Figure 1, II) and even the relationship between the more elementary stages of the corrosion process. For example, the general inhibition of the cathodic process may be separated into that caused by cathodic overvoltage and that caused by obstructed diffusion. Then the relationship may be determined between anodic inhibition, cathodic overvoltage, diffusion inhibition of the cathodic process, and ohmic inhibition, (i.e., R_A:r'_K:r''_K:R), as shown in Figure 1, III.

In some works,[3, 34] as well as in the authors' own investigations,[24, 35] it was shown that during the work of corrosion micro-cells the value of ohmic inhibition is insignificant and the corrosion rate is controlled by anodic and cathodic factors. If diffusion is quick enough (without noticeable passivation) then a characteristic feature of the process is the comparatively small value of anodic inhibition and large value of cathodic inhibition (Figure 2, I). To this type of processes reference may be made to the corrosion of iron and a number of other metals in chloride solutions (for instance, in sea water), and likewise to the corrosion of Fe, Al and other metals in diluted solutions of non-oxidizing acids.

During slow dissolution of passivated metals much greater importance is acquired by anodic inhibition which in this case may become commensurate with and even exceed the cathodic inhibition (Figure 2, II). To this type of process one may refer to the corrosion of iron in concentrated nitric acid or of stainless steels in most aerated salt solutions. As has been mentioned elsewhere,[37] the phenomenon of passivity may be defined most rationally as the reduction of the corrosion rate owing to increased anodic inhibition (control). In determining the degree of anodic control a quantitative characteristic of metal passivation may be given for the given conditions of corrosion. By this means the degree of passivity has been calculated for fifteen metals in an aerated 0.5 N NaCl solution (see Table 1).

The ohmic factor may be important enough when the main corrosive effect is determined not by the action of microcouples, but by that of macrocouples as often happens in soil corrosion when irregular aeration couples appear on elongated objects such as pipelines. Such cases will be interpreted by means of the polarizing diagram given in Figure 2, III. In atmospheric corrosion (electrochemical corrosion under a thin film of moisture), the ohmic and especially the anodic factors may play a significant part (Figure 2, IV).

Structural Heterogeneity and Metal Alloy Corrosion Resistance

Ever since the appearance of the electrochemical corrosion theory, justified importance was attributed to the influence of the alloy's structure on its corrosion behavior in electrolyte solutions.

If the surface of an ideally pure metal may (very relatively) be regarded as approaching homogeneity, the surface of a metal alloy will naturally always be heterogenous. For example, an extremely fine atomic heterogeneity exists in solid metallic solutions, and a coarser structural heterogenity in alloys of eutectic structure. Finally, there may be another kind of heterogeneity depending on the secondary evolution of a more positive cathode constituent on the corroding surface or conditioned by alloy liquation and other causes.[21, 24, 25]

It is important to determine the influence of such structural heterogeneity and the appearance of cathodic inclusions in the anodic alloy background on the corrosion behavior of alloys.

The influence of separate anodic inclusions in a cathode background does not present much interest for analysis as in this case the electrochemical heterogeneity will not remain for a long time. A separate anode isolated from the rest of the alloy structure will be first to dissolve and the alloy will acquire homogenous structure as shown in Figure 3 (I and II).

It is generally assumed that the heterogenous structure of a metal alloy automatically leads to the establishment of a greater corrosion rate. In a number of works,[38] low alloy stability is directly associated with the incidence of cathodic contaminations (microcathodes). Conversely, the absence of connection between the increase of cathodic impurities in the alloy and increased corrosion rate is often treated as a proof of the absence of electrochemical corrosion in the given case.

Analysis of the possible role of cathodic inclusions carried out on the basis of the modern theory of electrochemical corrosion, shows that the presence of cathodic inclusions in the alloy does not always lead to acceleration of the corrosive process. In the author's opinion, depending on the circumstances, the influence of cathodic inclusions on the rate of metal corrosion may be of the following four kinds:

1. Acceleration of corrosion due to electric current arising between the cathodic inclusion and the remaining anodic surface.
2. Greater acceleration of corrosion than justified by the current arising at contact with the cathodic inclusion.
3. Low effect of cathodic inclusions on the process of corrosion.
4. Reduction of corrosion rate under the influence of micro- or macro-cathodic inclusions.

A more detailed examination will be made below of these four cases of the action of heterogenous cathodic inclusions on the corrosion rate of a metal alloy in different conditions of corrosion.

Current Between Metal and Cathodic Inclusion

1. The appearance of microcathodes, the growth of their area or efficiency leads to an increase in corrosion rate proportional to the current arising between the metal and the given cathodic inclusion.

This most usual and obvious effect of micro- and macro-cathodes on the process of corrosion has been the object of extensive investigation. These investigations began with the hypothesis on the electrochemical dissolution of zinc in acid, proposed by De La Rive in 1830, extend through the numerous contemporary papers on metal corrosion and dissolution. A number of corrosive processes, such as dissolution of certain metals in non-oxidizing acids, are explained by such an accelerative effect of cathodic inclusions. Among these are the classic cases of zinc dissolution in diluted hydrochloric or sulfuric acid with the inclusion into their structure of Fe, Cu, Pb and other cathodic additions (see Figure 4). A similar acceleration of dissolution in nonoxidizing acids is observed in the cases of iron, steel and cast iron, under the influence of the inclusion of more noble cathodic constituents. For steel and cast iron the part of such microcathodes may be fulfilled, in particular, by inclusions of graphite, or iron carbides.

In all these cases the main controlling factor is the cathodic process, and the corrosion rate increases together with the area of cathodic inclusions. Another characteristic feature here is the increase of the rate of alloy dissolution with the accumulation of cathodic impurities on its surface (the existence of an induction period). If such a corrosion process is reproduced for example in a high purity zinc-platinum couple, it appears that the corrosion rate of such a model (Zn-Pt) will grow in proportion with the increase of current in the couple, because of the increase of cathode area. The straight dependence of the dissolution rate on the quantity of the cathodic structural constituent included into the metal may likewise be observed for certain alloys, especially with comparatively small additions of the cathode constituent (i.e., when the main controlling factor is cathodic overvoltage). Such increase of corrosion rate with the growth of the area of cathodic inclusions is possible not only during the cathodic process accompanied by hydrogen evolution, but also in corrosion associated with oxygen depolarization. However in the latter case it will be observed more seldom, namely, when the basic inhibition is determined not by oxygen diffusion but by overvoltage due to oxygen ionization.

Accelerated Corrosion

2. Cathodic inclusions accelerate corrosion to a greater extent than is justified by the corrosion current arising in the "metal-cathodic inclusion" couple.

Such effects of cathodic inclusions or cathode contact are observed in those metals and those conditions of corrosion when anode polarization causes additional activation of the basic metal. These phenomena will be observed primarily when the metal is considerably passivated, its corrosion potential therefore being greater than the equilibrium potential. They also will be found when anodic polarization, (for instance, owing to the presence of Cl^- ions in the solution) promotes depassivation. This phenomenon, known as the difference effect and experimentally established only for external cathode contact[9, 21] or polarization by external anode current[39] (Figure 5) must also be ascribed to the action of microcathodic inclusions. In the latter case the increasing number and size
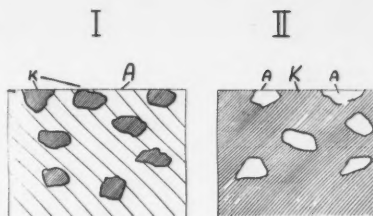
Figure 3—Two cases of structural electrochemical heterogeneity of the corroding alloy. I—Inclusion-cathode (K); Main background-anode (A). II—Inclusion-anode (A); basic background-cathode (K).
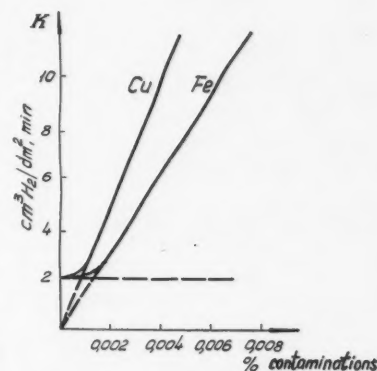
Figure 4—Influence of copper and iron contaminations on the dissolution rate of pure (99.992) Zn in a 1.8% H_2SO_4 solution. The dot-line is the possible continuation of the curve for absolutely pure, electrochemically homogenous Zn.

of cathodic inclusions in the alloy will accelerate corrosion to a greater extent than is justified by the corrosion current arising between the given inclusion and the remaining alloy surface. Additional acceleration of the process here is due to depassivation and to electrochemical or chemical corrosion occuring on new areas of the metal surface freed of protective film.

Such effects of cathodic inclusions ought to be supposed in the case of those metals which in certain conditions undergo the mentioned phenomenon of negative difference effect. The increased sensitivity of aluminum and magnesium to cathodic inclusions or more noble structural constituents while being corroded in diluted hydrochloric acid or chloride solutions must primarily be referred to such influence on the part of the microcathodes. Figures 6 and 7 are graphs showing the dependence of the corrosion rate of Al in HCl and Mg in 3 percent NaCl on the content of iron which in this case is the cathodic inclusion. As seen from the curves, the metal being contaminated with iron progressively accelerates corrosion.

Low Influence of Cathodic Inclusions on Corrosion

3. The low influence of cathodic inclusions on the process of corrosion is usually referred to the general case of diffusion inhibition of the process of cathodic depolarization due to oxygen ionization.

In this case the increase in cathode area due to the inclusion of cathodic constituents may not noticeably accelerate corrosion as the paths of diffusion of oxygen to separate earlier developed
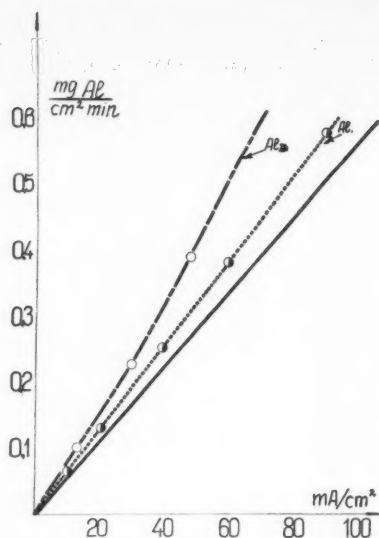
Figure 5—Dissolution rate of aluminum (Al) and Duralumin (Al_D) at anodic polarization in a 0.5N NaCl solution.[20]

Figure 7—Effect of iron contamination on corrosion rate of pure (99.998 percent) magnesium and Mg + 1 percent Mn alloy in a 3 percent NaCl solution (after H. Uhlig).

Figure 9—Corrosion diagram illustrating the possibility of facilitating passivation as a result of cathodic alloying.

Figure 6—Effect of iron impurity on corrosion rate of pure (99.998) aluminum in a 2N HCl solution (after M. Straumanis).
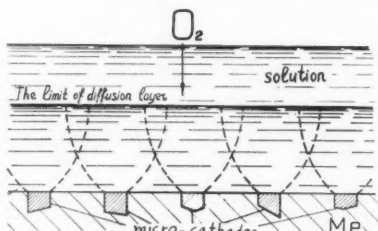
Figure 8—Paths of diffusion of depolarizer (O₂) to the microcathodes on the corroding surface (diagram).

and microcathodes thinly dispersed are superimposed one on the other. Thus the entire volume of the electrolyte in the diffusion layer adjoining to the metal surface is involved in the diffusion process, as shown in the diagram in Figure 8, and the further appearance of microcathodes may not noticeably increase the power of diffusion and accelerate corrosion. The small dependence of the rate of corrosion of such metals as iron or zinc in neutral solutions such as sea water on the degree of their contamination is determined by the aforementioned factor.

If the conditions of corrosion are such that cathodic and anodic control are commensurate, the effect of cathodic inclusions on the corrosion rate may also be low. This is due to mutual compensation between the cathode process facilitated by the relatively increasing microcathode area and the simultaneously developing obstruction of the anode process owing to the relative decrease in anode area, or to passivation.

Reduction of Corrosion Rate

4. Reduction of corrosion rate under the influence of developing or increasing microcathodic inclusions.

This less obvious effect of cathodic inclusions on corrosion does not, however, present anything exceptional. As shown by the results of investigations[3, 40] it is rather wide-spread and may be employed to increase the corrosion resistance of alloys.

This effect of cathodic inclusions on corrosion will be observed when there is a possibility of anodic passivation. In such cases the incidence of cathodic inclusions will further polarize the remaining anodic background. The latter's potential becoming more positive will facilitate passivation and render the passivity more stable. This will occur, however, only if the solution contains no active (i.e., depassivating) ions (e.g., Cl⁻).

The latter case of influence of cathodic structural inclusions bears the most practical interest, indicating a new way of obtaining corrosion resistant alloys quite contrary to way used now (i.e., not by reducing the cathodic structural constituents, but by intentionally including them into the alloy).

Conditions for Development of Metal Passivity

It was demonstrated earlier[3, 4, 24, 37] that the phenomenon of passivity in metal corrosion may justly be regarded as a case of anode passivity (i.e., passivity in regard to the anode process in the corrosive microgalvanic cell). In general, therefore, an alloy may become passive when there are conditions for anodic passivation of the anodic constituent.

Apparently, any reaction on the electrode discharging electrons into the outer circuit, must be regarded as an anodic process. Besides anodic ionization of metals such as

$$Me \xrightarrow{nH_2O} Me^{++} \cdot n\,H_2O + 2\theta \quad (1)$$
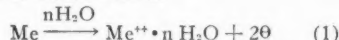
anodic processes may also include the
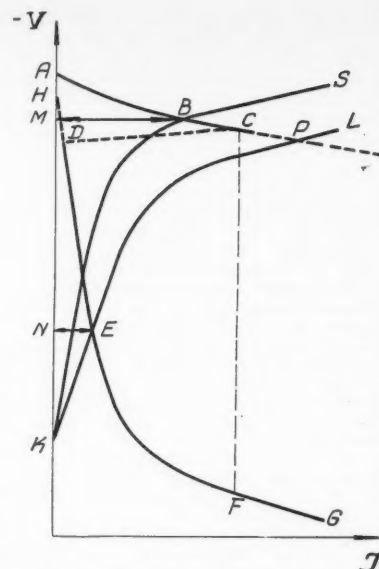
discharge of anions on the anode, (e.g., such reactions as the discharge of hydroxyl ions accompanied by the evolution of gaseous oxygen):

$$2\,OH^- \longrightarrow \frac{1}{2}O_2 + H_2O + 2\theta \quad (2)$$
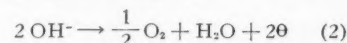
This process takes place at a considerably greater positive potential than the first (beginning at a + 1.23 volt potential with pH = 0).

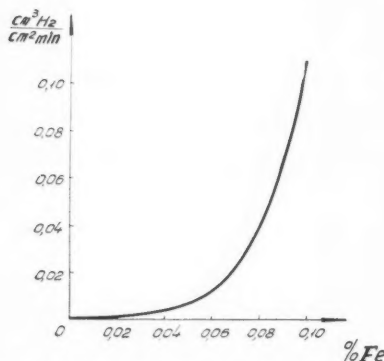According to modern concepts, anodic passivity is of the same nature as passivity in oxidizing media, without the impressed anode current. In other words it is explained by the appearance of a phase or adsorbate, (usually an oxide but sometimes a saline film) and the latter's screening[3, 4, 15, 21, 24, 49, 50] or electrochemically inhibiting[29] effect on the anode process. The film and absorption theories do not contradict, but complement each other. The analysis of experimental data shows that only by combining the film and adsorption theories of passivity is it possible to explain all the diversity of various cases of passivation. If the screening film passivation hypothesis is accepted it must also be accepted as true that the developing passive film does not let through metal ions (inhibits the anodic process of transfer of metal ions into the solution), but does not stop the passage of ions from the solution to the metal. This is confirmed by the possibility of such an anodic process as anion discharge, (e.g., evolution of oxygen on the anode.)

The appearance of oxide or hydroxide protective layers on the anode must also be regarded as an anodic process as shown below:

$$2\,OH^- + Me \rightarrow MeO + H_2O + 2\theta \quad (3)$$
$$2\,OH^- + Me \rightarrow Me(OH)_2 + 2\theta \quad (4)$$
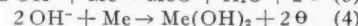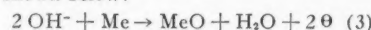
Such a point of view on the origin of anodic passivity makes it possible to calculate the potential to which the anode must be polarized to provide the thermodynamic possibility of passivation. Evidently, this will be the potential necessary for the anodic process of

oxide
tions
calcula
Thus
culatio
of th
Pt g
quen
minin
1N h
of wh
react
othe
tial
matic
to se
tion
catho
which
electr
activ
—0.2
ing a
anod
while
form
tainm

Su
iron
value
anod

Co

Th
alloy
able
may
rosio
ABC
izatio
passi
and
of C
the
the
being
of th
show
men
and
alrea
curv
expe
with
This
catho
cross
the z
The
the
abse
dete
appe
on t
ing)
incre
case
ably
Figu
in th
case
by s
less
an a
clusi

It
cien
unde
pass
ence
activ

oxide or hydroxide film formation-reactions (3) or (4). This potential may be calculated from thermodynamic data. Thus, for reaction (3) approximate calculation based on analysis of the action of the reversible cell Ni| NiO| acid| H₂, Pt gives a potential of +0.11. Consequently, the potential +0.11 will be the minimum potential (in respect to the 1N hydrogen electrode) the attainment of which will make possible the anodic reaction of nickel oxide formation. In other words, this is the minimum potential which will make possible the formation of protective oxides not owing to secondary processes such as interaction between the products of anodic and cathodic processes Me⁺ and OH⁻, but which occur as a result of primary anodic electrochemical oxidation. So, if there is an active nickel electrode with a potential of —0.25 in the beginning, the electrode during anodic polarization, will undergo the anodic process of nickel dissolution, while the anodic process of oxide film formation will start only after the attainment of the potential +0.11.

Such calculations carried out for an iron anode[24, 37] gave a minimum potential value of —0.081 for the beginning of the anode process of Fe₃O₄ film formation.

Corrosion Resistance Increased by Cathodic Inclusions

The essential possibility of increasing alloy resistance (in conditions of probable passivation) by cathodic inclusions may be explained by means of the corrosion diagram shown in Figure 9. Here ABCDEFG is the curve of anode polarization in conditions of probable anodic passivation.* When the current density and electrode potential reach the level of C, anodic passivation takes place and the current in the circuit drops to D, the subsequent intensive polarization being caused by the anodic polarization of the passive metal. The curve GFEDH shows the return or repetitive movement of the anodic polarization curve and indicates certain stabilization of the already developed passivity. KBS is the curve of cathodic polarization at the expense of the alloy's own cathodes without the addition of active cathodes. This curve indicates comparatively high cathodic polarization. The curve KBS crosses the anodic polarization curve in the zone of electrode activity in point B. The local current, which conforms to the rate of electrode corrosion in the absence of additional cathodes, will be determined by segment MB. With the appearance of additional active cathodes on the metal surface (e.g., through alloying) cathode efficiency will considerably increase. The cathode curve for this case (KEPL) which indicates considerably lower polarization, as shown in Figure 9, crosses the anode curve only in the passive zone (point E). In this case the corrosion current is determined by segment NE and is of considerably less value than the corrosion current for an alloy without additional cathodic inclusions (segment MB).

It is easy to see that with insufficiently increasing cathode activity or under conditions unfavorable for anodic passivation, for instance with the presence of Cl⁻-ions in the solution, the active zone of the anode curve extends

*The anodic polarizing diagram being obtained experimentally, with a high ohmic milliammeter, its course may be modified to the curve ABCFD.

Figure 10—Corrosion rate of chromium-nickel stainless steels (18 percent Cr and 8 percent Ni) alloyed with cathodic additions (Pt, Pd, Cu) depending on H₂SO₄ concentration. Trial length—360 hours, temperature 20C.

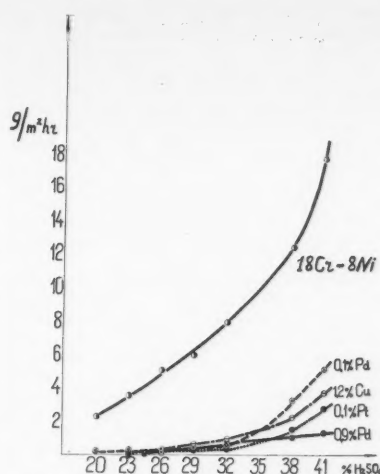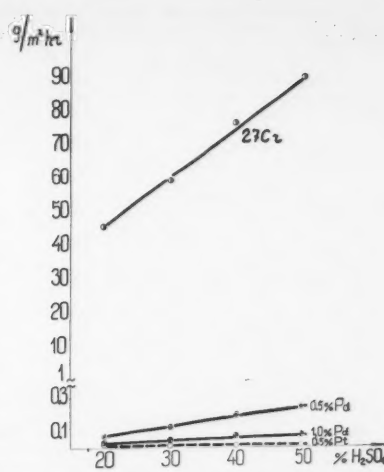to very large current densities curve ABCP. In this case the increase of cathode area will be accompanied by the usual growth of local current (up to the level of point P), and consequently by accelerated corrosion. The diagram also shows that if the alloy becomes more resistant due to anode passivation, the measured potential (determined by point N) will be considerably more positive than the potential of any alloy deprived of additional effective cathodes (point M). The degree of cathode control in this case considerably decreases and anodic control may become prevalent as in Figure 9.

To check experimentally the possibility of increasing alloy corrosion resistance by introducing cathodic structural constituents, investigations were made[40] of austenitic chromium nickel steel containing 18 percent Cr and 8 percent Ni. This is a readily available alloy, whose high corrosion resistance is wholly determined by its passivity.

The basic type of steel was used in four new experimental brands of steel which were smelted with special inclusions of cathodic constituents. In addition to the elements commonly used in this type of steel, the four samples contained: No. 1—0.1 percent Pt, No. 2—0.1 percent Pd, No. 3—0.93 percent Pd, No. 4—1.2 percent Cu.

Investigation of the stainless steels alloyed with cathodic inclusions showed their comparatively easier passivation. Figure 10 shows the results of comparative corrosion tests of common and cathodic alloyed steels in H₂SO₄ solutions of different concentration. It was found that all steels alloyed with cathodic additions and especially steels including additions of such cathode effective metals as Pt and Pd possess considerably higher corrosion resistance in sulfuric acid than steels not alloyed with special inclusions.

Besides introducing cathodic structural constituents into the alloy it also is advisable to increase the passivity of the anodic background. Pure iron is also easier passivated with the introduction of cathodic structural constituents. However the passivation of pure iron is not high enough and the positive effect of such cathodic alloying will be

Figure 11—Corrosion rate in H₂SO₄ of chromium steels with 27 percent Cr alloyed with cathodic inclusions (Pt or Pd). Duration of test was 100 hours, temperature was 20C.

observed only in concentrated strongly oxidizing mediums (HNO₃, and in neutral solutions free from Cl⁻ with abundant oxygen supply).

For chromium nickel steels containing 18 percent Cr and 8 percent Ni in solid solution this process of passivation, as demonstrated, goes on much easier. Passivation of such steels with platinum alloying is achieved even in 30 percent H₂SO₄ solutions. It may be assumed that further addition of chromium to the solid solution will facilitate passivation still more at the expense of the newly included cathodic structural constituents. Experiments have shown that in the case of straight chromium steel with 27 percent Cr and without nickel, the passive state is made more stable by additional cathodic alloying.

Figure 11 shows that at additional cathodic alloying of such steel with platinum (0.5 percent) or palladium (0.5 percent or 1.0 percent) the extention of the stable passivity zone is accompanied by considerably increased corrosion resistance in H₂SO₄ solutions. However, the corrosion resistance of stainless steels may be increased only to a certain limit by raising their potential to more positive values. The study of the behavior of stainless steels and iron, recently conducted by Akimov, Kurtepov, Batrakov,[36, 41, 42] as well as the results of French investigations[51] show that the corrosion resistance of these metals in strong oxidizing mediums, becomes considerably reduced, despite the potential being shifted to more positive values. The mechanism of this phenomenon known as transpassivation has until recently received no explanation.

Only in recent publications has an experimentally proved explanation been given to this phenomenon[43, 44]. It was found in the cases of certain metals, including chromium, that if the potential is shifted far enough in the direction of positive values, an anodic process may take place with the production of high valency soluble oxide compounds of the anodic metal[52]. In the case of chromium there occurs an anodic reaction of the following kind:
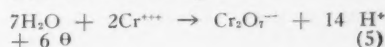
$$7H_2O + 2Cr^{+++} \rightarrow Cr_2O_7^- + 14\ H^+ + 6\ \theta \qquad (5)$$
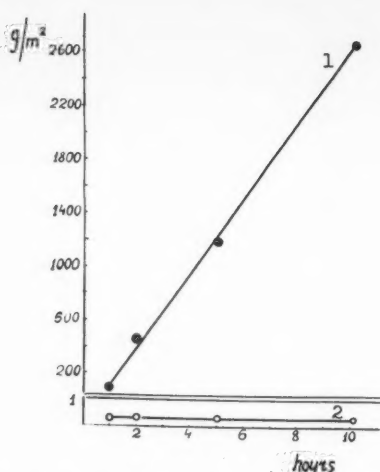
Figure 12—Effect of anodic polarization on corrosion of 18-8 steel in 50 percent H_2SO_4 at 50C. Line 1 is for steel corrosion without anodic polarization; Line 2 is for steel corrosion at anodic polarization with current density 2.5 $\mu a/cm^2$.

TABLE 2—Effect of Anodic Polarization on the Corrosion Rate of Type 18-8 Stainless Steel in Sulfuric Acid

H_2SO_4 Concentration in Percent	Temperature, Degrees C	Anode Current Density in $\mu a/cm^2$	Corrosion Rate in gr/m^2 per Hour
30	18	10	0.06
30	18	0	4.0
30	50	2.5	0.1
30	50	0	53
50	50	2.5	0.15
50	50	0	217
60	50	2.5	0.15
60	50	0	183

which leads to the production of soluble hexavalent chromium compounds in the form of $Cr_2O_7^{--}$ ions. This process goes on quite smoothly without any noticeable overvoltage at a potential of $+1.36$ volt. For chromium reaching this potential, an anodic process of chromium dissolving with the formation of $Cr_2O_7^{--}$ ions will take place. This will occur whether this potential is reached for chromium because of anodic polarization or increased oxidizing potential of the medium. The anodic process of O_2 evolution does not take place at this potential owing to considerable oxygen overvoltage on the anode. As the corrosion resistance of stainless steels is determined by the phase or adsorption film developing on the basis of chromium oxides, the film being transformed into soluble chromium oxide will lead to continuous chromium dissolution with the formation of $Cr_2O_7^{--}$. This will lead to the loss of corrosion resistance on the part of the steel, despite the very positive potential value.

It follows from the proposed mechanism of transpassivity that anodic polarization (or additional cathodic alloying) will not reduce the rate of dissolution of transpassive steel. On the contrary, cathodic polarization or additions of deoxidizer, (i.e., different ways of lowering the oxidizing-reductive potential of the medium), may transfer the steel from its transpassive state into a pas-

234t

sive condition and consequently will increase its corrosion resistance.

From the cited investigations[48] as well as from the recently published independent works of G. Edeleanu[53], there develops the basic possibility of employing anodic polarization from external current sources for protecting stainless steels in sulfuric acid solutions. The data received by the authors (Table 2 and Figure 12) show that the current densities required for sustaining the passive state of steel are not very large (0.01 — 0.1 a/m²).

Electrochemical protection of stainless steel (18Cr-8Ni) in sulfuric acid requires its potential to be maintained at values of from $+0.5$ to $+1$ volt (referred to the hydrogen electrode). Lesser values of the anode potential will leave the danger of incomplete passivation. A higher anode potential will somewhat accelerate anodic steel dissolution due to increasing current density.

Apart from sulfuric acid solutions, such protection apparently may be carried out in a number of other media where stainless steel becomes active, but only if the steel may be passivated by anodic polarization and if the passivity obtained may be kept stable. This method of electrochemical protection might also be used for a number of other readily passivated metals and alloys. Anodic electrochemical protection may be effected only if it is possible to establish stable anodic passivity and to maintain the latter with comparatively low anode current densities.

Ways of Increasing Metal and Alloy Corrosion Resistance

Departing from the nature of electrochemical corrosion, the following main ways for increasing the corrosion resistance of metal alloys may be noted (see also Table 3):

1. Production of alloys developing a better protective (screening) layer of corrosion products on their surface.
2. Maximum reduction of alloy cathode activity.
3. Maximum reduction of alloy anode activity.

The three mentioned ways of producing highly corrosion resistant alloys consist respectively in influencing three main corrosion controlling factors. The first is ohmic and diffusional inhibition; the second and third, are respectively, cathodic and anodic activity.

Alloys With Better Protective Layers

The production of alloys developing a better protective layer of corrosion products provides comparatively limited means of increasing electrochemical corrosion resistance. The reason evidently is that the products of electrochemical corrosion cannot provide complete enough screening, while partial screening will be inadequate because ohmic inhibition is usually not the main controlling factor. Noticeably better protection may be expected from the condensation of protective films in cases when the process takes place in atmospheric conditions. As an example, reference may be made to the increased corrosion resistance of copper when alloyed with zinc or aluminum, (i.e., the higher corrosion resistance of brasses and aluminum bronzes as compared to pure copper). The increased resistance of steels containing Cu as compared to common steel must also, to a consider-

able extent, be explained by the condensation of corrosion products, although in this case the main part is played by anodic inhibition. However, this method ought to be the chief means of increasing alloy resistance to high temperature gas corrosion.

Reduction of Alloy Cathodic Activity

Reduction of alloy cathodic activity offers much greater possibilities for improving the anti-corrosive properties of metallic systems. The first method to be considered is the reduction of the cathode phase in the corroding alloy structure, a method which has long been popularized by corrosion engineers. In this connection reference may be made to Figures 4, 6 and 7 where there is considerable reduction of the corrosion rate of zinc, aluminum, magnesium and iron in diluted acids after the reduction of cathode effective inclusions in these metals or in derivative alloys. Sometimes even the most common thermic processing through which the cathode inclusions are introduced into the solid solution, is found to be quite useful from the point of view of corrosion resistance. It is known that Duralumin tempering which transfers the cathodic inclusions of $CuAl_2$ into the solid solution, considerably increases the corrosion resistance of this alloy in chloride solutions. A similar effect on corrosion has been noted at the tempering of carbon steels when the rate of the metal's dissolution in non-oxidizing acids being reduced after the cathodic inclusions of iron carbides are transferred into the solid solution.

Apart from reducing the area of cathodic inclusions, the general cathodic activity of an alloy may be lowered by increasing the cathode overvoltage.

By way of illustration mention should be made of the reduced dissolution rate of zinc contaminated with cathodic inclusions of Fe, Cu, Al etc. after cadmium alloying[54] or surface amalgamation. According to Kroenig[45] and others, it is evident that additional (0.5-1 percent) manganese alloying of technical magnesium and certain other homogenous magnesium alloys with considerable inclusions of Fe, noticeably lowers the rate of their corrosion in NaCl solutions (Figure 7). This is doubtlessly determined by increased hydrogen cathode overvoltage on the microstructural constituent with the introduction of manganese into the alloy. It also may be supposed that slight arsenic or antimony alloying (in the order of 0.2-2 percent) of steels will reduce their dissolution rate in non-oxidizing acids[55,56] as arsenic tends to considerably increase hydrogen overvoltage on the cathode.

Reduction of Alloy Anode Activity

Reduction of alloy anode activity offers the greatest possibilities of producing electrochemically corrosion resistant alloys.

From the corrosion viewpoint it is extremely desirable that the strengthening constituent in constructional metal alloys should be anodic in respect to the basic background. In most cases, as for instance in carbon steels and especially in high-strength aluminum alloys as Duralumin, this is not observed. An exception is magnalium, a high strength aluminum alloy with magnesium, where the strengthening constituent Al_2Mg_3 is anodic in respect to the main background.

For this reason the latter alloy possesses

sesses increased corrosion resistance as compared with Duralumin, because the separate inclusions of anodic constituent Al_2Mg_3 quickly become dissolved in its structure and the surface is brought to a state of electrochemical homogenity as shown in Figure 3, II.

Another important means of opposing corrosion by reducing the anode phase area is the removal of strain stress from the alloy surface. It is known now[3, 8, 46] that corrosion cracking and corrosion fatigue are determined by active anode areas appearing at the bottom of the developing corrosion crack.

In some cases reduction of intercrystallic corrosion in alloys is achieved by reducing the anode area, when obtaining an alloy structure with more clear-cut boundaries by alloy purification or appropriate thermal treatment. This is done in the same manner as with stainless steels or as demonstrated by S. E. Pavlov in respect to high-strength aluminum alloys with 59 percent Mg.[47]

Apart from reducing the anode areas, the alloy anodic activity may be lowered by reducing the efficiency of the anodic process itself. The latter may in the first place be achieved through increasing the thermodynamic stability of the alloy by introducing a large quantity of a more noble constituent into a solid solution of the alloy. As a rule, in this case corrosion stability increases by leaps, the amount of noble constituent atoms in the alloy reaching $\frac{1}{8}$, $\frac{2}{8}$, $\frac{3}{8}$ or $\frac{4}{8}$ of the total content (the known n/8 rule proposed by Tamman[2, 26]). An example of this kind is gold alloying of copper, nickel alloying of steel; the latter, for instance, is effected when pure chromium steels are transformed into chromium nickel steels.

Instead of increasing the thermodynamic stability of the anode stage, in certain cases a positive effect may be obtained by alloying with elements increasing anode phase passivity (e.g., chromium alloying of iron (production of chromium steel), silicon alloying of iron (production of high silicon cast iron), chromium alloying of nickel or its alloys). It is noteworthy that usually a marked increase of passivation likewise is observed when the content of chromium atoms in the alloy reaches a value which is equal to $\frac{1}{8}$ (or any multiple of $\frac{1}{8}$) of the total number of atoms; for instance for chromium steels this is achieved at a chromium content of 12.5, 25 and 37.5 atomic percent, (i.e., with 11.8, 23.7, and 35.8 weight percent of Cr).

Therefore, in this and the preceding case alloying gives a positive effect only with considerable quantities of the noble or passivating constituent.

The addition of 0.3-1.0 percent of titanium or Nb to stainless steels, which prevents the carbon in the steel from extracting chromium from the solid solution (i.e., eliminates chromium impoverishment of grain boundaries and the appearance of intercrystalline corrosion), must also be referred to alloying inclusions increasing the passivation of the anode phase.

In conclusion mention should be made of one more means of reducing corrosion rate by lowering anode efficiency: addition of active cathodes to the alloy. In conditions enabling the establishment of a passive state (absence of Cl^- ions in the corrosive medium and anode phase passivation), additional inclusion of effective cathodes even in small quantities (0.1-0.5 percent) may lead to

alloy passivity owing to increased anodic polarization of the basic anode background.

Which of the examined methods of increasing corrosion resistance is better may not be said directly, without considering concrete circumstances. This or that method may be found preferable depending on the service conditions of the given metal alloy.

For economic reasons it is not always possible to increase the thermodynamic stability of the anode phase. To do so requires the use of noble constituents which is uneconomic and not always practicable. Indeed, the production of an alloy of the solid solution type (which is absolutely obligatory for obtaining a corrosion resistant alloy on these principles) is not always possible due to the restricted mutual solubility of solid constituents in a number of systems.

In acid corrosion under deoxidizing conditions accompanied by hydrogen evolution it is unreasonable to try to increase alloy resistance by stimulating passivation. It may be found useful, however, to reduce alloy cathodic efficiency or to increase the thermodynamic stability of the anode phase. When passivation is possible, reduction of cathode

efficiency becomes impracticable, while all methods of reducing anode activity, additional cathodic alloying in particular, will be found useful. The latter possibility, almost never considered before, has been experimentally and theoretically established, in the present paper.

Conclusions

The present paper examines the general laws governing the increase of corrosion resistance of metallic systems by means of alloying.

1. The reduction of corrosion resistance by the introduction of cathodic inclusions into the alloy is observed if the process of the corrosion is controlled by overvoltage of the depolarizing cathode reaction. With corrosion controlled by oxygen diffusion, cathode inclusions do not markedly accelerate corrosion. When it is possible to establish prevalent anodic control, cathodic inclusions may promote passivation and consequently considerably reduce the rate of corrosion.

2. The degree of passivity may be regarded as a value equivalent to the degree of anodic control effected in the given process. Therefore a new method for calculating the degree of passivity of different metals may be proposed.

TABLE 3—Possible Ways of Increasing Metal Alloy Corrosion Resistance

General Procedure	Specific Methods	Typical Applications
Production of alloys with better screening layer of corrosion products.	Introduction of constituents promoting the formation of denser protective films on alloy surfaces.	(a) Aluminum alloying of copper.
		(b) Zinc alloying of copper.
		(c) Molybdenum alloying of stainless steels for increasing resistance to Cl^- ion-containing solutions.
		(d) Copper alloying of low grade steels.
		(e) Chromium, aluminum and silicon alloying of iron for increasing heat-resistance.
Reduction of alloy cathode activity.	Reduction of microcathode areas.	(a) Increased resistance of zinc, aluminum, magnesium, iron and some other metals when dissolved in HCl and H_2SO_4 (for magnesium also in NaCl) observed with increased purity.
		(b) Transfer of cathodic inclusions into the solid solution as for instance, during tempering of Duralumin or carbonaceous steels.
	Increase of cathodic overvoltage (usually hydrogen overvoltage).	(a) Amalgamation of technical zinc.
		(b) Cadmium or zinc alloying of contaminated zinc.
		(c) Manganese or zinc alloying of technical magnesium.
		(d) Arsenic or antimony alloying of steel to increase resistance in acid.
Reduction of alloy anode activity.	Reduction of anode phase area.	(a) Production of alloys, preferably of the magnalium type whose strengthening components is the anode and whose main background is the cathode.
		(b) Purification of alloy grain boundaries (tempering, reduction of impurities).
		(c) Removal of external or internal strain stresses, both constant and alternating (elimination of corrosion cracking and corrosion fatigue of brasses, high-strength steels and magnesium and aluminum alloys).
	Introduction of constituents increasing the thermodynamic stability of the anodic phase.	(a) Gold alloying of copper.
		(b) Copper alloying of nickel.
		(c) Nickel alloying of steel (chromium steel in particular.
	Introduction of constituents increasing passivation of anode phase.	(a) Chromium or silicon alloying of iron.
		(b) Chromium alloying of nickel or its alloys.
		(c) Addition of constituent preventing escape of chromium from the solid solution (e.g. Ti, Nb, Ta into stainless steels).
	Introduction of active cathodes (in conditions of possible passivation).	(a) Additional alloying of stainless chromium and chrome-nickel steels with small inclusions of Pt, Pd, Ag and Cu.
		(b) Inclusion of copper into low alloy steel (at atmospheric corrosion).

Approximate calculation of the passivity of certain metals in aerated 0.5N NaCl solutions gives the following order of reduction of degree of passivity: Ti-Al-Cr - Be - Mo - Mg - Ni - Co - Fe - Mn - Zn-Cd-Sn-Pb-Cu.

3. Passivation of the metal or alloy may begin only when the anode areas reach the potential required for the anode reaction associated with the formation of a phase or adsorbate passivating oxide. The potential required for the beginning of passivation of a nickel anode in acid mediums (NiO formation) calculated from thermodynamic data is $+0.11$ volt for an iron anode (formation of Fe_3O_4), -0.081 volt referred to a hydrogen electrode.

4. The possibility of increasing alloy corrosion resistance by additional cathodic alloying was interpreted by analyzing the polarization diagram.

5. The possibility of increasing the corrosion resistance of readily passivated metallic system was experimentally tested on chromium-nickel (18Cr-8Ni) and straight chromium (27 Cr) steels additionally alloyed with Cu (1.2), Pd (0.1-1) or Pt (0.1-0.5 percent). During tests in hot and cold sulfuric acid solutions of different concentration, the steels additionally alloyed with cathodic inclusions were more readily transferred into a passive state and were much more resistant than the same steels not alloyed with additional inclusions of cathodic structural constituents.

6. The transpassivity of stainless chromium and chromium-nickel steel (i.e., the reduction of their corrosion resistance in such excessively oxidizing media as 60 percent $HNO_3 + 10$ percent $K_2Cr_2O_7$) was explained by the formation of hexavalent soluble chromium oxide in the case when the steel potential becomes more positive than $+1.36$ volt. Transpassivity occurs regardless of whether the said potential value is achieved through anodic polarization or by increasing the oxidizing capacity of the medium. Cathodic polarization, which shifts the potential towards less positive values, may convert transpassive stainless steel into a passive state.

7. Analysis of the conditions of passivation of stainless steel showed that in a number of corrosive media (for instance sulfuric acid solutions), anodic polarization may be employed as a method of corrosion prevention. A necessary condition of anodic electrochemical protection is the possibility in the given conditions of establishing and maintaining passivity at comparatively low current densities. The corrosion rate of stainless steel (18Cr-8Ni) at its anodic polarization with a current density of $0.01 - 0.1$ a/m² and a surface potential of from $+0.5$ to $+1.0$ volt (referred to hydrogen electrode) in 60 percent sulfuric acid at a temperature of 50C was negligible (thousands of times less than in the absence of cathodic protection).

8. On the basis of modern theoretical conceptions the following ways of increasing metal alloy corrosion resistance must be considered practicable:

a. Production of alloys with a better screening layer of corrosion products (ohmic and diffusional corrosion inhibition).

b. Reduction of alloy activity by lowering the microcathode area or by adding constituents increasing the cathodic overvoltage. This method is applicable if in a given metallic system and supposed working conditions it is impossible to attain the firm passive state.

c. Reduction of alloy anodic activity by reduction of anodic phase area; introduction of constituents increasing thermodynamic stability of anodic phase; introduction of constituents increasing passivation of anodic phase; introduction of active cathodes in alloy (if existence of alloy passive condition is possible).

Depending on the conditions of service and the concrete metallic systems, one or another of the examined methods may prove more or less practicable and advantageous.

References

1. M. V. Lomonossov. Collected works, v.1, Acad. of Sciences U.S.S.R., 1950.
2. G. Tamman. Lehrbuch der Metallkunde. Leopold Voss, Leipzig, 1932.
3. U. Evans. Metallic Corrosion, Passivity and Protection, Edward Arnold and Co., London, 1946.
4. C. Wagner and W. Traub. Elektrochem., 44, 391, 1938; C. Wagner. Chemische Reaktionen der Metalle. Handbuch der Metallphysik, Bd. I. Leipzig, 1940.
5. O. Bauer, O. Kröhnke and G. Masing. Die Korrosion metallischer Werkstoffe, Bd. I, II, III, S. Kizzel, Leipzig, 1940.
6. F. N. Speller. Corrosion; Causes and Prevention. McGraw-Hill, 1935. U.S.A.
7. J. C. Hudson. Corrosion of Iron and Steel. Chapman and Hall, 1940, London.
8. H. Uhlig. The Corrosion Handbook. John Wiley and Sons, New York, 1948.
9. Tödt. Korrosion und Korrosionsschutz. Berlin, 1955.
10. R. H. Brown and R. B. Mears. Trans. Electrochemical Soc., 81, p. 455, 1942.
11. R. Pope. Corrosion, 11, No. 4, 189t (1955) Apr.
12. R. B. Mears. Corrosion, No. 8, 362t (1955) Aug.
13. T. P. May, F. LaQue. Corrosion, 10, No. 3, 91, (1954) Mar.
14. R. H. Brown and R. B. Mears. Trans. Faraday Soc., 35, 467, 1939.
15. V. A. Kistyakovsky. Electrochemical Reactions and Electrode Potentials of Some Metals. Trans. St. Petersb. politechn. Inst., 1910.
16. N. A. Izgarishev. Diseases of Metals and Ways of Their Conservation. GIZ, 1922.
17. N. A. Izgarishev. Agressive Media and Metal Corrosion in Chemical Equipment. M., 1939.
18. N. A. Izgarishev. Electrochemical Theory of Metal Destruction. M., 1946.
19. A. N. Frumkin. Trans. II Conference on Metal Corrosion AS USSR.
20. A. N. Frumkin. V. S. Bogotsky, Z. A. Yofa, B. N. Kabanov. The kinetics of Electrode Processes. M., 1952.
21. G. V. Akimov. Metal Corrosion. Theory and Methods of Investigation. Ac. Sci. USSR. M., 1945.
22. G. V. Akimov. Principles of the Theory of Corrosion and Metal Protection. Metallurgizdat, 1945.
23. G. V. Akimov et al. Studies on Electrochemical and Corrosion Behaviour of Metals and Metal Alloys. Oborongiz, 1950.
24. N. D. Tomashov. The Theory of Metal Corrosion. Metallurgizdat, 1950.
25. N. D. Tomashov. Metal Corrosion with Oxygen Depolarization. Ac. Sci. USSR, 1947.
26. V. V. Scorcelletti and A. I. Shultin. Chemical Destruction of Metals. ONTI, 1935.
27. Ya. Y. Durdin. Trans. Leningrad State Univ., 1939, 49, 3 J. Gen. Chem., 1951, 21, 801.
28. A. I. Shultin. J. Phys. Chem., 15, 370, 399 (1941); 18, 61, 69 (1944).
29. Ya. M. Kolotirkin and A. N. Frumkin. J. Phys. Chem., 15, 346 (1941).
30. Ya. M. Kolotirkin. J. Phys. Chem., 25, 1248 (1951).
31. V. V. Scorcelletti. Metal Corrosion (Supplement to work by G. A. Kashchenko, Principles of Metallurgy. Metallurgizdat, 1950).
32. N. D. Tomashov. The Theory of Atmospheric Metal Corrosion. Achievements of Chem., 19, No. 6, 716 (1950).
33. N. D. Tomashov. Corrosion Controlling Factors. DAN, 52, No. 9, 791 (1946).
34. V. G. Levich, A. N. Frumkin, J. Phys. Chem., 15, 748 (1941)
35. N. D. Tomashov, M. A. Timonova. J. Phys. Chem., 22, No. 2, 221 (1948).
36. B. P. Batrakov, G. V. Akimov. DAN, 89, 321 (1953).
37. N. D. Tomashov. DAN, 88, No. 4, 705 (1953); No. 6, 1023 (1953).
38. D. O. Slavin, E. B. Shteiman. Metals and Alloys in Chemical Machine Building. Machgiz, 1951, p. 217.
39. N. D. Tomashov, V. N. Modestova. Trans. Inst. Phys. Chem. Ac. Sci. USSR, 1, No. 2, 42 (1951).
40. N. D. Tomashov, G. P. Chernova. DAN, 89, 121 (1953).
41. M. M. Kurtepov, G. V. Akimov. DAN No. 6, 87, 93, 795, 1005 (1952).
42. M. M. Kurtepov, G. V. Akimov, N. N. Bardish. DAN, 87, 625 (1952).
43. N. D. Tomashov, G. P. Chernova. DAN, 98, 435 (1954).
44. V. P. Batrakov. DAN, 99, 97 (1954).
45. V. O. Kroenig, S. E. Pavlov. Trans. VIAM, 1935, No. 30.
46. A. V. Ryabchenkov. Corrosion Fatigue of Metals. Machgiz, 1953.
47. S. E. Pavlov. Problems of Sea Corrosion (coll. ed. G. V. Akimov) Ac. Sci. USSR, 1951, p. 58.
48. N. D. Tomashov, G. P. Chernova. DAN, 104, No. 1, 104 (1955).
49. T. H. Heumann, W. Rösener. Zeitschrift für Elektrochemie, Bd. 57, No. 1 (1953).
50. H. J. Rocha, G. Lennartz. Archiv fur Eisenhüttenwesen, No. 2, 117 (1955)
51. J. M. Defranoux. Rev. Metal, 49, 664 (1952).
52. S. Glasstone. An Introduction to Electrochemistry. New York.
53. G. Edeleanu. Nature, 17, 739, (1954); Metallurgia, 50, 113-116 (1954).
54. M. Straumanis. Korrosion und Metallschutz, 3, No. 11, 49, 1935.
55. G. Vegesack. Stahl u. Eisen, 74, No. 11, 735 (1954).
56. O. Binder, C. R. Bishop. U. S. Patent 2,678,881, May 18, 1954.

Any discussions of this article not published above will appear in the June, 1958 issue

Electrical Measurements and Their Interpretation In Underground Cable Corrosion Problems*

By K. G. COMPTON

About the Author

K. G. COMPTON has worked with corrosion problems for more than 25 years at the Bell Telephone Laboratories, Murray Hill, N. J. During World War II he was a consultant on the deterioration of materials to the NDRC and the Chief of Ordnance; he has also been active on corrosion committees of several technical societies. It was at the State College of Washington that he received his training in electrical and chemical engineering and in electrochemistry.

Introduction

THE ELIMINATION of trolley systems in many cities has made it necessary to find improved methods of making underground cable corrosion surveys. Many of the methods formerly employed for electrolysis mitigation have proved ineffective under the new conditions. The purpose of this paper is to discuss some techniques applicable to the new conditions, their limitations, when they may be used, and the significance of the data obtained. Each of the general techniques can be interrelated with one or more of the others since by itself it may not give adequate information. The necessity for supplementing one technique with another will appear in the discussion of the examples.

The principal reasons for making electrical measurements are: (1) To locate points at which corrosion current leaves the cable sheath, and (2) If cathodic protection is applied, to determine if the cable is adequately protected.

Since corrosion is electrochemical in nature, the rate of corrosion is related to the current which passes from the cable sheath to the environment converting metallic metal into ions. One faraday or 96,500 ampere-seconds of current is required to dissolve one equivalent weight of the metal. It does not follow, however, that all current leaving a cable produces corrosion. Other reactions also can occur such as the evolution of oxygen or the electrolytic oxidation of some substance at the surface of the cable sheath. The flow of current to or from the lead sheath changes the potential at the sheath-soil interface by what is known as polarization. It is measurements of potential that show this polarization effect that reveal the passage of current to or from the cable sheath.

Some practices and the associated terminology that have developed in underground corrosion work over the years tend to be misleading. For instance, the term "cable to earth potential" leads the uninitiated to believe that the voltage that is measured is actually that between the cable and the earth. Actually the cable-to-earth measurement is the potential difference of a cell composed of the cable, the moist earth as an electrolyte and a reference electrode as shown in Figure 1. The reference electrode used in underground corrosion work may be a lead slug, water pipe, steel pin, copper-copper sulfate half cell or other electrode having a low resistance electrolytic contact with the earth.

Similarly, the practices of connecting the cable to the positive terminal of the meter, or of referring to raised-earth, or

remote earth, lead to confused thinking. The stray current "electrolysis" man must always contend with polarities, yet frequently he has difficulty with the comprehension that the negative electrode corrodes where the cell is of galvanic origin. This difference between internal and external sources of potential is illustrated in Figure 2. An understanding of this difference between stray current and galvanic situations is a prerequisite to correct interpretation of corrosion data.

Consider a series of underground cables each affected by a different type of corrosion. In Figure 3 stray street railway current which has been picked up by a cable discharges from the cable to travel through the earth back to the railway at some point near a power station.

Figure 4 shows a typical example of galvanic corrosion resulting because of cables being bonded to a water distribution system having copper service pipes. The copper acts as the cathode of a cell with an internal source of potential as shown in Figure 2. The long corrosion cell shown in Figure 5 is similar in that the source of potential and the corroding area is more negative to the reference electrode than is the area receiving current. The source of potential may be differences in concentration and kind of soil electrolyte such as would be encountered by a cable passing from a sandy soil into a clay soil or from a gravelly loam into a marshy soil.

In the three examples above, the anodes and cathodes are separated by appreciable distances and a significant current flows in the cable sheath. The

Abstract

Methods of making duct surveys, surface potential gradient surveys, measurements of cable to reference electrode potentials, sheath current measurements and earth resistivity measurements are described. Examples are given of various types of measurement and their interpretation. It is pointed out that a single measurement of the potential between a cable sheath and a reference electrode in contact with nearby earth may not reveal the existence of a corrosive condition. Emphasis is given to the difference in polarity between self-produced corrosion cells and those resulting from external influences such as stray current or contact with a more noble metal. The importance of employing a variety of measurements in any particular study is shown. References are given to techniques employed by other workers in making underground corrosion tests. 4.5.3

difference between the long corrosion cell of Figure 5 and the local corrosion cell of Figure 6 is one of distance between anodes and cathodes. In local corrosion cells such as produced by differential aeration, these distances may be very small, sometimes approaching microscopic size. Neither the currents, nor the potentials, are measurable by any practical means.

In trying to locate the corroding area and to determine the cause of the corrosion by means of electrical measurements, several techniques have been used. Usually the selection of techniques is determined by the physical situation encountered at the site. The same is true of measurements used in conjunction with the adjustment of a cathodic protection system. The techniques can be classified broadly as:

1. Duct surveys.
2. Cable to surface electrode measurements.
3. Surface potential gradient measurements.
4. Null bridge potential measurements.
5. Sheath current measurements.
6. Resistivity measurements.
7. Measurements of potential or current with respect to foreign structures.

Reference Electrodes or Half Cells

A reference electrode in the broadest sense is any metallic body in contact with an electrolyte such as a salt solu-
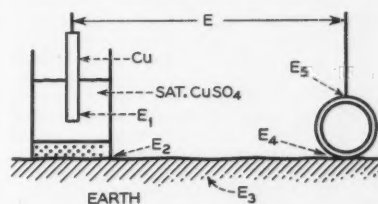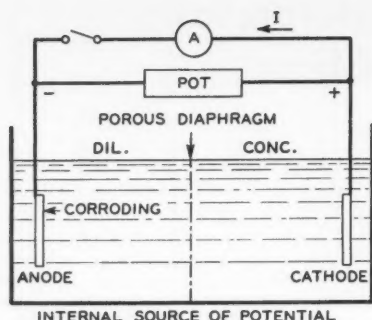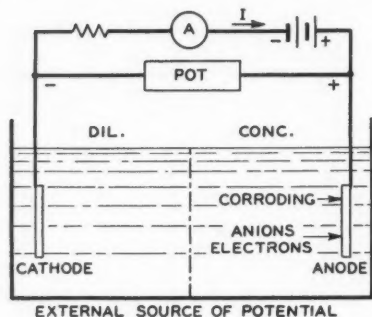

Figure 1—Schematic of structure to half cell potential measurements.

Figure 2—Polarities in corrosion cells.

INTERNAL SOURCE OF POTENTIAL

EXTERNAL SOURCE OF POTENTIAL

Figure 3—Stray current to a foreign structure.

Figure 4—Galvanic cell corrosion currents between dissimilar metals.

Figure 5—Long cell corrosion currents.

Figure 6—Local cell corrosion currents.

tion or moist earth, to which measurements of potential are made as a reference point. It is assumed to be fixed and the other electrode is looked upon as variable. In bygone years the reference electrode was a steel plate, steel ground rod, a lead slug, or any other piece of base metal. Such electrodes do not have a fixed potential relationship with moist earth, so for more accurate work a means for making an ionic contact is used which is termed a half cell.

In the Daniel Cell or simple wet battery composed of an electrode of zinc and another of copper immersed in a mixture of zinc and copper sulfate solutions, the open circuit potentials at the interfaces between the metals and the solution are very definite and constant. If either one of these electrodes and the solution surrounding it is placed in a container having a porous bottom so that electrical contact can be made with the earth, a half cell is the result. The potential between the metal and the solutions will be relatively constant and usually the contact potential between the solution in the porous bottom of the container and the moist earth will be negligible or constant. Then the variable member of a cell composed of a metallic body such as a cable sheath, moist earth and a half cell will be the electrolytic contact potential between the metallic body and the earth. This is shown in Figure 1 where E is the measured potential and E_1 is the constant potential between copper and the saturated copper sulfate solution. E_2 is the liquid junction potential between the copper sulfate solution and the soil electrolyte. E_3 is a composite potential made up of various liquid junction potentials in the soil and any IR drop that is present. E_4 is the contact potential of the structure to the soil and is the potential being studied. It is composed of two essential parts, the open circuit or static potential and a polarization potential. E_1, E_2 and E_3 are not exactly constant or reproducible
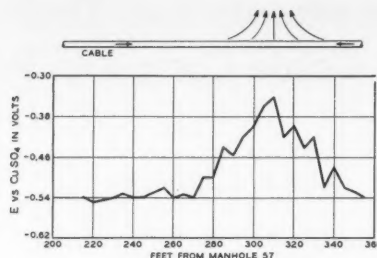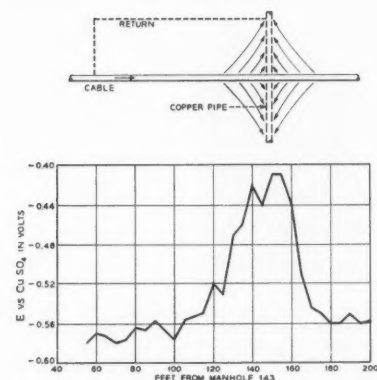
in practice and constitute a limitation on the precision of the measurements.

A large number of different reference electrodes or half cells have been developed for laboratory use but the copper-saturated copper sulfate electrode has received the greatest acceptance for field measurements. It is universally used by the pipe line industry. The lead-lead chloride electrode was used in the telephone system, but variability in the potential from one half cell to another was experienced even though the units were made up at the same time and from the same materials. Scott Ewing[1] made a study of the copper sulfate and cadmium sulfate electrodes and it was on the basis of his work that the copper sulfate half cell has attained widescale use in the field. Both the calomel and the silver chloride electrodes have been used in the field in addition to those mentioned above.

Duct Surveys

In a duct survey,[2] a reference electrode is pulled or pushed through an empty duct in a subway and measurements of the potential between the cable of interest and the reference electrode are made at intervals of about three feet. Lead slugs generally are used for this purpose. Half cells have been used in duct surveys but care must be exercised to avoid contamination of cable sheath surfaces with a more noble metal, such as copper from the copper sufate electrode. The author has used the calomel and the silver chloride half cells in duct surveys to avoid contamination. Where a lead slug is used, the current and resistance between the cable grid and the slug sometimes are measured in addition to the potential. Under some conditions the duct survey gives information which permits a fairly ac-
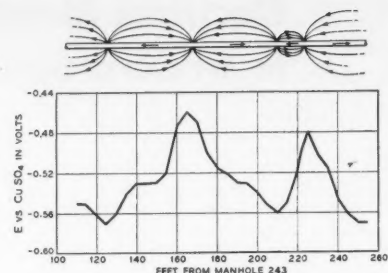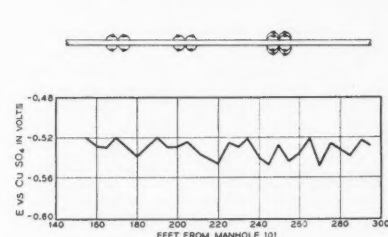
curate appraisal of the corrosion conditions. In other cases, the shielding effect of other cables, and the indeterminate resistance through the duct walls renders the information inconclusive or confusing.

Very often in a nonstray current area, a duct survey will not reveal a corrosive condition if the action is confined within the duct and is due to short cells such as those produced by differential aeration. However, from the appearance of a cable that has failed, it may be decided that cathodic protection is needed. Duct surveys in this situation will aid in establishing the amount of current required and its proper distribution. Usually protection is achieved if the cable-to-slug potential is shifted to 0.20 volt negative or the cable is made 0.70 volt negative to the copper sulfate electrode.

In a duct survey with a lead slug, the information obtained is somewhat different from that obtained with a half cell since the slug potential tends to vary with the environment and the passage of time as the measurement is made. If a long section of cable sheath is uniformly positive to a lead slug or somewhat less negative than —0.62 volt to the copper sulfate half cell, it may be passive and not experiencing corrosion. Similarly an indication of current flowing in the metallic circuit from the cable to the slug may mean that the slug is negative to the cable in that environment and is discharging current to the cable as a shortcircuited galvanic cell. This condition would result from the fact that the corroded sheath is cathodic to the uncorroded slug (see Figure 2).

Where the cable potential is appreciably positive to the slug (>0.2 volt) it is likely that the cable is discharging current due to a stray field or from a galvanic effect due to bonding to a more noble structure such as copper water pipe. In this connection reference should be made to Figures 3 and 4 where representative potentials to a copper sulfate half cell are shown.

The anodic and cathodic areas of the long electrolytic cells shown in Figure 5 also may be located. In this situation
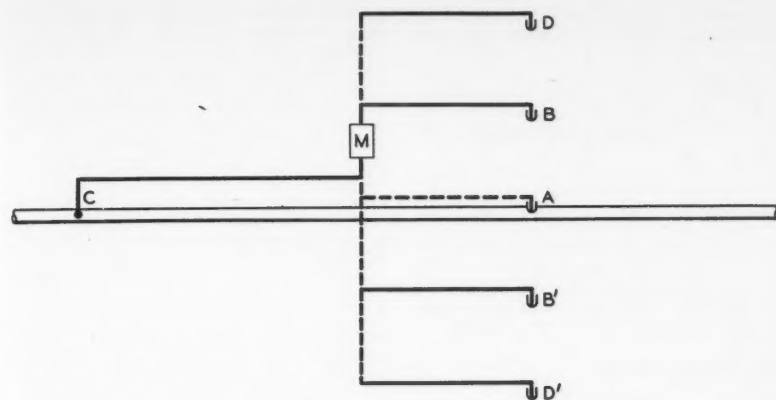
METER READING IN VOLTS					REMARKS
1	$\dfrac{C-A}{-0.58}$	$\dfrac{C-B}{-0.64}$	$\dfrac{C-B'}{-0.63}$	$\dfrac{C-D}{-0.70}$ $\dfrac{C-D'}{-0.68}$	CABLE DISCHARGING CURRENT
2	$\dfrac{A-B}{+0.060}$	$\dfrac{A-B'}{+0.050}$	$\dfrac{A-D}{+0.120}$	$\dfrac{A-D'}{+0.100}$	
3	$\dfrac{C-A}{-0.58}$	$\dfrac{C-B}{-0.50}$	$\dfrac{C-B'}{-0.51}$	$\dfrac{C-D}{-0.42}$ $\dfrac{C-D'}{-0.41}$	CABLE RECEIVING CURRENT
4	$\dfrac{A-B}{-0.080}$	$\dfrac{A-B'}{-0.070}$	$\dfrac{A-D}{-0.160}$	$\dfrac{A-D'}{-0.170}$	
5	$\dfrac{C-A}{-0.58}$	$\dfrac{C-B}{-0.64}$	$\dfrac{C-B'}{-0.51}$	$\dfrac{C-D}{-0.70}$ $\dfrac{C-D'}{-0.41}$	TRANSVERSE CURRENT
6	$\dfrac{A-B}{+0.060}$	$\dfrac{A-B'}{-0.070}$	$\dfrac{A-D}{+0.120}$	$\dfrac{A-D'}{-0.170}$	

Figure 7—Lateral potential gradient measurements.

Figure 8—Surface potential gradient measurements.

Figure 9—Schematic of zero resistance ammeter method of cable sheath current measurement.

the more negative areas of the sheath will be the anodes and the more positive areas will be cathodic. It is possible, in any particular location, that several types of cells may be present simultaneously. Little hope can be offered in these cases unless one type dominates in the corrosion process.

Cable to Surface Half Cell Measurements

This method is applicable to buried and underground cables when some of the earth's surface is exposed above the cable or nearby. It consists of making contact to the cable and determining the potential difference measurements between it and a reference electrode placed at one or more positions as nearly above the cable as possible.

The data in Figures 3 to 6 are examples of cable to surface half cell readings. Where current discharge from the cable is suspected from the potential readings, a determination of potential of two points equally spaced to either side of the cable will usually provide a verification. If the lateral readings[1] are more positive than those over the cable, current is flowing away from the cable. More negative readings indicate current flow to the cable and one positive with the other negative indicates a transverse flow of stray current which may not be affecting the cable at all.

[1] It is customary to refer to the potential of the cable with respect to the half cells in the various locations. Thus an IR drop added to the potential of the cable to a half cell would make the cable more positive to a half cell located to one side if current were flowing in the direction of the half cell.

Typical examples of lateral potential gradient readings are given in Figure 7. Two methods are shown, one in which a contact is made to the cable and readings made to a half cell placed over the cable and to each side, and the other in which measurements are made between two half cells as shown.

Without cathodic protection the interpretation of the data is essentially the same as in a duct survey. In the presence of cathodic protection, errors due to IR drop are introduced which must be taken into account. In some cases these errors may be reduced by using the Pearson null bridge to balance out the IR drop. An estimation of the magnitude of the IR drop errors may be obtained by means of surface potential gradient measurements and allowances made for them.

A potential between the cable and a copper sulfate reference electrode of less than 0.40 volt (cable negative) usually indicates a current loss area, as in Figure 3, rather than a cathodic condition. Between —0.40 and —0.62 volt is an uncertain area in which the cable sheath may be either anodic or cathodic. In a corrosion cell resulting from dissimilarities of the environment in contact with the cable, as shown in Figure 5, the cathodic areas on the sheath would tend to approach the —0.40 volt potential, whereas the anodic areas would approach a potential of —0.62 volt, the average open circuit potential of lead in soils. Polarization due to the corrosion current would tend to pull the two values toward each other.
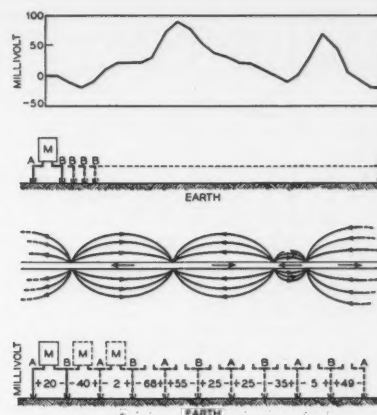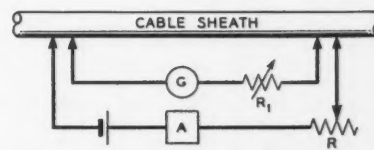
Surface Potential Gradient Measurements

Surface potential gradients are determined by measuring the potential between two indentical[2] half cells in contact with the moist earth surface. These gradients indicate the direction of current flow in the earth and to some extent the magnitude of the current. The measurements may be made successively over the cable along its length, as in Figure 8, or laterally, as in Figure 7, depending upon the information desired.

Both Mudd[4] and Werner[5] have given papers on this technique. The former established a structure-to-surface electrode potential and then proceeded in a leap-frog manner to take electrode-to-electrode measurements over the structure (in this case a pipeline). He then added these values algebraically to determine changes in the potential of the structure to surface electrode.

Werner placed one electrode on the surface of the earth at some selected spot and proceeded to make measurements between this electrode and a roving electrode moved to successive positions over the cable. He also employed the lateral and equally spaced measurements to verify current discharge from the cable. Both of these techniques are shown in Figure 8.

The present author uses surface gradient measurements in a more general manner depending upon the circumstances encountered. In some instances a composite of the Mudd, Werner and cable-to-surface measurements described above, is used. In examples 2 and 3 given below, the field use of surface potential gradients is illustrated. Reference can be made to the papers by Mudd[4] and Werner[5] for other examples.

At points where the surface half cell over the cable is most positive will be

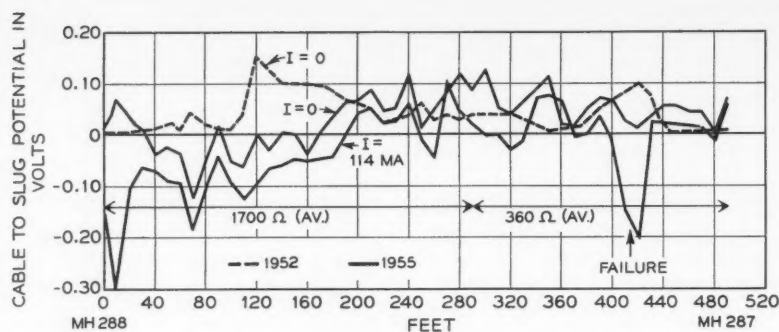[2] The difference in the potential of the two half cells should not exceed 5 milli-volts.

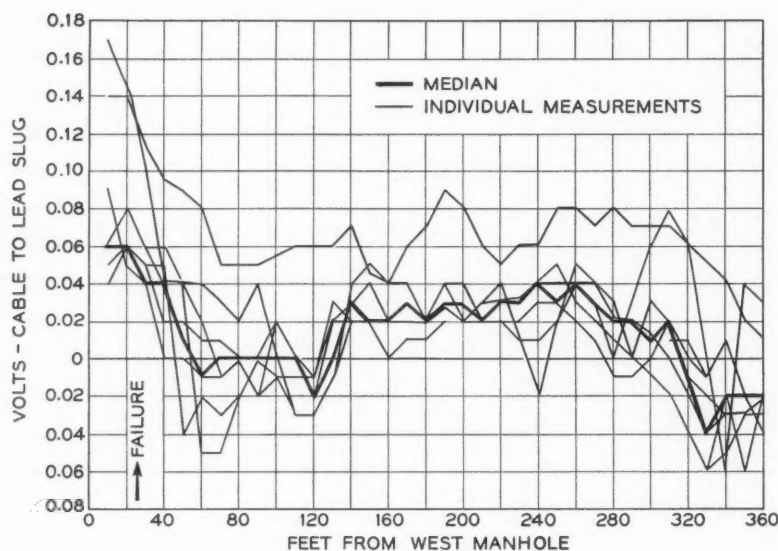Figure 10—Duct survey with and without cathodic protection.

Figure 11—Duct surveys in multiple duct subway.

the greatest loss of current from the cable (assuming uniform earth resistivity), irrespective of whether the corrosion is due to long cell galvanic effects or to stray current. It should be pointed out that Werner connects his fixed cell to the positive terminal of his zero center meter as he does to his cable, a custom of long standing among telephone electrolysis engineers, so that negative values in his curves indicate that the roving half cell is positive to the fixed half cell. This must be kept in mind in determining the direction of current flow, and whether the cable is tending to be anodic or cathodic.

Null Bridge Potential Measurements

The null bridge as developed by Pearson, Hadley and Logan[2] is useful in making measurements of the potential difference between a cable and a reference electrode in contact with soil in connection with the determination of the current required for cathodic protection. It will eliminate the component of IR drop that is in the common circuit and is produced by the current through the earth between the far electrode and the cable. For the effect of other components of IR drop and the null bridge circuit see Appendix 1.

In determining the current required

to give protection, the null bridge is set up and balanced, then the cathodic protection current from the anode bed to the structure is increased from a very low value, in steps. The potential is read at each value of current. As described by Logan[3] the break in the voltage-log current curve is the point at which protection is reached. Usually a small factor of safety is provided by operating at about 100 millivolts more negative than this potential.

Sheath Current Measurements

Usually sheath currents are determined by measuring the millivolt drop over a length of cable sheath and translating this into current from the nominal resistance of the sheath for a particular diameter and length of section.

A more precise method is that known as the "zero resistance ammeter method."[(3)] One description of a "zero resistance ammeter" circuit has been given by Werner[6] as a report of NACE Technical Committee T-4B. The basic circuit of the method is given in Figure 9. The null instrument can be a millivoltmeter,

(3) This circuit has been given various names in the many years since it was first conceived. The present name is employed by most corrosion engineers.

a galvanometer or a device consisting of a chopper, amplifier, rectifier and indicator. The sensitivity is limited by the reproducibility of the microvolt readings of the null instrument. Since the resistance of a two foot section of a full size cable sheath is of the order of two tenths milli-ohms, the detection of differences in current of one milliampere would require a reproducible sensitivity of about two tenths microvolt per division for the null instrument. At such a sensitivity considerable trouble could be expected from thermoelectric potentials.

The currently available instruments are limited to the detection of currents in a two foot section of full sized sheath of something greater than 10 milliamperes. Where longer sections of cable can be tapped, the sensitivity is increased accordingly. Measurements with presently available instruments are laborious and time consuming. The author has a circuit using an electronic galvanometer that will detect one milliampere in a full sized cable sheath.

In measuring current by the zero resistance ammeter method, contacts are made to the cable sheath as shown and R is adjusted until the null instrument G reads zero on its most sensitive range. At this setting, it is assumed that there is no current flowing through the cable sheath between the current contacts to cause a deflection of G and the entire cable sheath current passes through and is read on the ammeter A.

The usual practice is to measure the current at two ends of a cable section to determine if a loss of current has occurred in between. In addition, measurements of the sheath current will show whether cathodic protection is reaching the desired cable in a group. In some situations cathodic protection currents can be adjusted until no loss is indicated by sheath current measurements, where potential measurements are impractical. A discussion of sheath current analysis and the method of measurement was given by Fouts.[7] His methods were used in Example 2. Other current measurements are made at bonds to foreign structures either by measuring the drop across a shunt that is used for the bond or by inserting an ammeter in the circuit.

Resistivity and Resistance Measurements

Soil resistivity and resistance are measured with a variety of instruments available on the commercial market. Soil resistivity is a specific property expressed either in ohm-centimeters or in meter-ohms. It is of value in comparing soils in one area with those in another and in some cases can be used to predict probable areas of corrosion. Very often where resistivity measurements are made along an underground structure and where a section with exceptionally low resistivity is found, corrosion is experienced in the same area. Resistance is usually measured between two structures or between a lead slug and the cable bank. In duct surveys, this measurement between the slug and the cables indicates whether a cathodic protection current can be useful in shifting the interface voltage of a cable within a duct or manhole.

Examples

In Figures 3 to 6 several typical examples of causes of corrosion are shown. In the situation in Figure 3 the location of the current discharge point can be determined by means of a duct survey,

cable to surface electrode measurements, or by surface potential gradient measurements. If the surface of the earth is covered with paving so that direct contact to it cannot be made, only the first technique is practical. If the cable is in duct, the current in the cable sheath can be measured and the loss determined. Potential measurements will show a more positive potential at the point of greatest current loss than will be found on either side.

Verification of the current loss can be made by the lateral potential measurements described above. In the case of Figure 4 the same techniques would be used as in the case of the stray current. The interpretation of the measurements would be similar, but more emphasis would be placed on measurements to the surface of the earth over and to each side of the cable, in order to locate the cause of the trouble. In Figure 5 the interpretation of the potentials of the cable to a half cell would be opposite to the preceding two situations. Corrosion would be occurring where the cable is most negative. In Figure 6 none of the techniques described would reveal corrosion in a positive manner.

Field Example 1

After a cable failure in a manhole section of the subway in a residential section of a small city, a duct survey was made with the results shown in Figure 10 by the dashed lines. Previous to the failure, leaks had occurred between 120 and 160 feet from manhole 288 and also at 420 feet, which had been repaired after excavation and breaking into the duct. The final failure occurred at 415 feet and the cable was replaced. It will be noted that at both of these locations in the first survey, the cable was significantly positive to the lead slug. There was some uncertainty as to whether this trouble was due to a long cell produced by the cable sheath itself or to the presence of numerous new copper pipes passing under the subway from a water main in the street to the residences along the street front, which were electrically connected to the cable. To prevent future trouble it was decided to install a cathodic protection system using graphite duct anodes in a spare duct in the section.

The cathodic protection system was installed and energized at a current of about 100 milliamperes for six months, then a new survey was made with the results shown by the solid lines in Figure 10. In addition to potential measurements between the cable and slug, the current and resistance to slug were measured also. The resistance measurements clearly indicated the flooded section of the subway beyond 290 feet from manhole 288. To supplement the duct survey, null bridge measurements were made at several points along the cable. These indicated that the cable was not protected at 114 milliamperes, but would be protected with a current between 350 and 450 milliamperes. The results of the null bridge measurements are shown in Table 1.

Field Example 2

In another urban location a cable failure was experienced in a 15 duct subway, containing seven lead sheathed and two alpeth sheathed cables. A duct survey was made which was composed of measurements of cable to slug potentials. The resistance between slug and

cable grid, and the current between the slug and the cable grid were measured.

Individual measurements of cable-to-slug potential and the median are shown in Figure 11. These data do not reveal the cause of failure nor did the current and resistance measurements.

In the duct where the cable failed a heavy current to the slug was encountered at the point of failure, but equally large currents were found flowing both to and from the slug at other points. A series of measurements of the potential of the cables to a reference electrode placed on the earth surface was equally inconclusive in revealing the cause of failure but did indicate a positive condition near the west manhole. These data are given in Figure 12. Null bridge measurements near the west end of the section indicated a pronounced potential gradient towards a parking lot south of the subway. This was discovered by balancing the bridge at several positions of the far half cell south of the cable which gave a result similar to that in Figure 19(c), but of opposite polarity. Measurements between a fixed half cell placed over the cables and a roving half cell to the south produced the data given in Figure 13. The numbers on the curves are the distances in feet east of the manhole at which the lateral gradients were measured.

These data indicate a heavy flow of current to some buried object eight to ten feet south of the cables and other current coming in from the parking lot. An excavation laterally south of the point of failure revealed a carbon-rich fill as shown in Figure 14. This fill was highly conducting both in its mass and back to the cable grid. The resistance between a ground rod thrust into it and the cable grid was less than three ohms, whereas a similar measurement to adjacent soil was 100 times greater. It was now apparent that the carbonaceous mass was acting as the cathode in a giant underground battery and was connected to the cable grid through water and gas mains in contact with it.

Duct anodes were installed and measurements made to determine if the carbonaceous mass would draw an excessive share of the protection current. Both surface potential gradients and current entering the sheath at both ends of the section were determined with the protection current on and off. The current measurements shown in Figure 15 indicated that the protection currents in a large measure entered the section from outside to return to the negative rectifier lead. This figure represents three manhole sections of the cable grid, that on the left being west of the section in which failure occurred.

A composite of all the cable sheath currents is given at the bottom of the figure. It will be noted that the sum of the currents on the two sides of any bond is not equal to zero. There is evidence of interchange of current between cables within the section. These observations indicate a decided limitation on the significance to be attached to small values of current difference. However, in this instance the magnitude of the current returning to the negative connection of the cathodic protection system from the second manhole to the east confirms the conclusion that insulating joints are required in the cable sheath at both the east and west manholes shown and the laterals. These joints are needed to prevent waste of current by
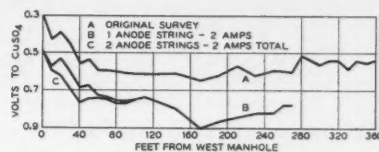

Figure 12—Axial cable to half cell survey. Graph shows potential of the cable to a half cell on the surface over the cable.
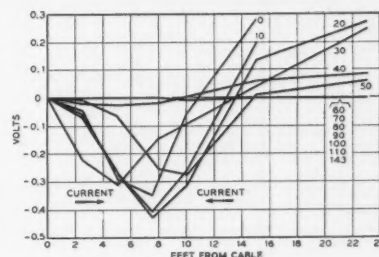

Figure 13—Potential of roving half cell to fixed half cell placed over the cable.
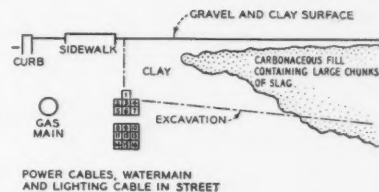

Figure 14—Cross-section at point of cable failure.

discharge from the duct anodes to the carbonaceous fill and back through the water mains. This is further confirmed by the presence of currents from the subway to the fill as indicated by surface potential gradient measurements with the anodes energized.

Figure 12 shows the effect on the potential of the cable to a copper sulfate half cell over the cable with the protective current both off and on but without insulating joints in the sheath. Figure 16 shows the position of a water main to which the cable was bonded and which acted as the conductor from the carbonaceous fill to the cable grid.

Field Example 3

In a city where a high rate of cable failure existed in one section of the business district, it was felt that a cathodic protection system might be effective. Because the earth resistivity is very low it was decided to employ two or more groundbeds and to adjust the current supplied from each to give protection to all cables in a wide downtown area.

Duct surveys were out of the question because the entire underground plant was under water and the pumping required would be extremely costly. There were very few places where contact could be made to the earth over the cable so a combination of cable-to-surface half cell and null bridge measurements was employed.

In the course of the tests it was found that manhole walls tended to insulate the cables they contained and separate cathodic protection was required within the manhole. In one critical section of the city, the null bridge measurements indicated a lateral potential gradient
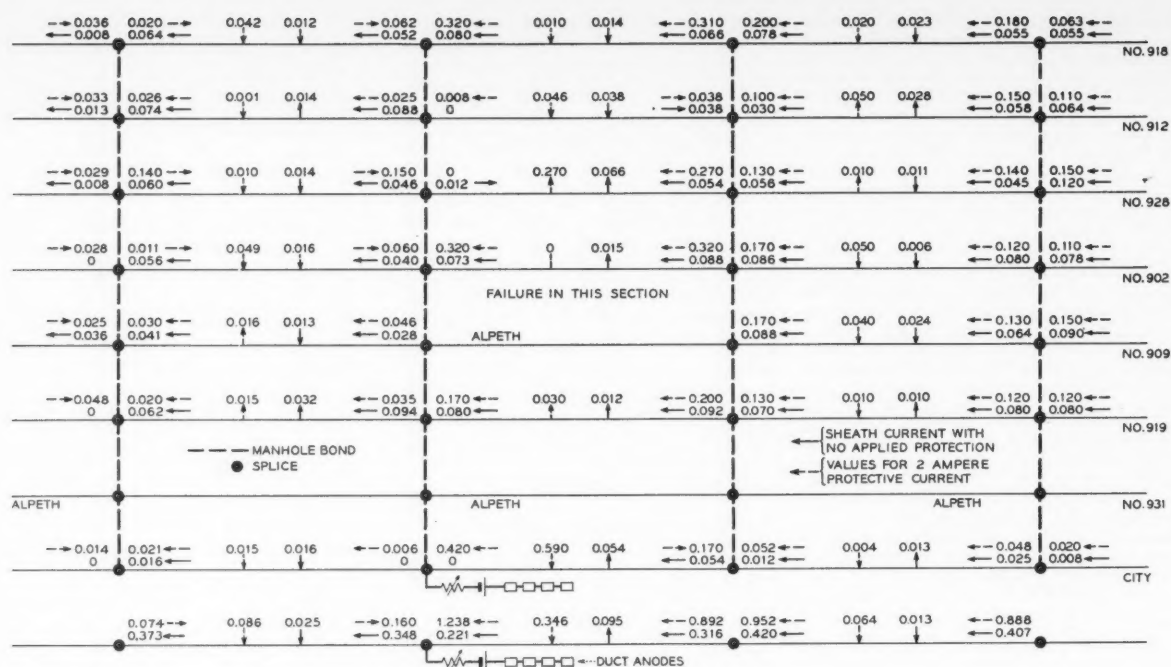
```
  -→0.036   0.020→       0.042   0.012    -→0.062   0.320     0.010   0.014    ←0.310   0.200←     0.020   0.023    ←0.180   0.063
  ←0.008    0.064←                          ←0.052   0.080                      ←0.066   0.078                        ←0.055   0.055      NO. 918

  -→0.033   0.026 ←—     0.001   0.014    ←—0.025  0.008      0.046   0.038    -→0.038   0.100     0.050   0.028    ←—0.150  0.110
  ←0.013    0.074←                          ←0.088   0                         -0.038   0.030                        ←0.058   0.064      NO. 912

  -→0.029   0.140        0.010   0.014    -→0.150   0          0.270   0.066    ←—0.270  0.130     0.010   0.011    ←—0.140  0.150 ←—
  ←0.008    0.060                           ←0.046   0.012                      ←0.054   0.056                        ←0.045   0.120      NO. 928

  -→0.028   0.011        0.049   0.016    -→0.060   0.320      0       0.015    ←—0.320  0.170     0.050   0.006    ←—0.120  0.110 ←—
  0         0.056                           ←0.040   0.073                      ←0.088   0.086                        ←0.080   0.078      NO. 902

                               FAILURE IN THIS SECTION

  -→0.025   0.030 ←—     0.016   0.013    ←—0.046             ALPETH            0.170←            0.040   0.024    ←—0.130  0.150←—
  ←0.036    0.041                           ←0.028                              0.088                               ←0.064   0.090←—      NO. 909

  -→0.048   0.020 ←—     0.015   0.032    -→0.035   0.170      0.030   0.012    ←—0.200  0.130     0.010   0.010    ←—0.120  0.120←—
  ←0.062    0.062                           ←0.094   0.080                      ←0.092   0.070                        ←0.080   0.080      NO. 919

                                                                                        ←—  SHEATH CURRENT WITH
       ----- — MANHOLE BOND                                                             ←—  NO APPLIED PROTECTION
              ● SPLICE                                                                  ←—  VALUES FOR 2 AMPERE
                                                                                        ←—  PROTECTIVE CURRENT

  ALPETH                                             ALPETH                                        ALPETH           NO. 931

  -→0.014   0.021        0.015   0.016    ←—0.006   0.420←—    0.590   0.054    -→0.170   0.052     0.004   0.013    ←—0.048  0.020←—
  0         0.016                           0         0                         ←0.054   0.012                        ←0.025   0.008      CITY

              ───〜�Ⱶ─[□□□]─
     0.074→         0.086   0.025    -→0.160   1.238←—   0.346   0.095    ←—0.892  0.952←—    0.064   0.013    ←—0.888
     0.373←                                  0.221   0.348                    ←0.316   0.420                        ←0.407
              ───〜〈Ⱶ─[□□□]─ ←—DUCT ANODES
```

Figure 15—Cable sheath currents. Arrows show direction of current flow. Currents are given in amperes.

when the cathodic protection system was not energized.

Surface potential gradient measurements between two half cells as shown in Figure 17 indicated a current flowing from the street curb to the alley. The numbers over the arrows in Figure 17 indicate the IR drop in volts between two half cells placed at the small circles. The polarity of the electrodes is indicated and the arrows designate the direction of current flow. Subsequent investigation disclosed a buried bare copper neutral from a direct current power distribution system in the alleys. Since all underground structures were bonded together, it was necessary to provide sufficient current from the cathodic protection system in the area to overcome this undesirable condition.

During this survey an interrupter was employed to turn the various rectifiers off and on in several combinations. The rapid shift in potential to stable values made it apparent that IR drop errors could not be eliminated by the current interruption method sometimes employed by other workers.

Typical readings are shown in Table 2 which indicate that protection has been achieved in most locations. Locations 11 and 12 were at a considerable distance from the ground beds and indicate that an additional ground bed will be needed in that area. The good agreement between the three readings assures that large IR drop errors are not included. Measurements of the cable potential to copper sulfate half cells in the manhole corresponding to 1 and 2 showed a change of —.13 to —.19 as the rectifier was turned on and similarly for 3 and 4 a change from —.18 to —.38. This clearly shows the insulating effect of the manhole walls and as failures had been experienced in the manholes, that sacrificial anodes were necessary in some of them.

Field Example 4

In another area of the country two failures were experienced on lead sheathed underground cable. After the cables had been repaired a survey was made by measuring the potential of the cable to a half cell over the cable at regular intervals. The results of this survey are given in Figure 18. It will be noted that the average potential to one side of the failure points was about —.44 volt with four peaks of —.40 volt to —.35 volt. The potentials at the points of failure were —.49 volt and —.50 volt respectively with an average in the area of about —.49 volt. Voltage drop measurements on the sheath indicated a current from the more positive area in each direction with some variability of direction at scattered points. From the current direction and the fact that corrosion did not occur at the more positive sections, it must be concluded that the corrosion was due to a long cell produced by variations in the soil through which the cable passed. From the current direction and potential measurements between cable and half cell it is likely that additional failures will occur north of station 38.

Discussion

From the examples given it is apparent that a single measurement of the potential of a structure to a reference electrode in contact with the earth does not give very conclusive information unless the structure appears highly positive or highly negative to earth. In the former case there is little question but that a stray current is discharging from the structure and in the latter, that the structure is receiving current and is being cathodically protected.

In the first field example, two duct surveys three years apart gave somewhat contradictory results. The first survey indicated trouble in areas somewhat positive to adjacent areas, whereas in the second, the areas of trouble were less positive. The fact of corrosion led to the installation of cathodic protection, and potential measurements were used to establish the amount and distribution of current required.

In the second example, the duct survey was completely inconclusive in establishing the cause of the corrosion. Surface potential gradients aided in establishing the cause of corrosion and were used in adjustment of the cathodic protection current. The cable to half cell measurements would have indicated a dangerous area near the manhole and would have suggested stray current as the cause. This would tend to be confirmed by the cable sheath current measurements. The lateral measurements disclosed the local galvanic cell composed of the carbon and the cable sheath.

In the third example, the reason for making potential measurements was to determine the proper current output for two separate cathodic protection installations and the effective distribution of the protection. As a by-product of the measurements it was found that the manhole walls were insulating and that a stray current existed in one area.

In the initial survey single cable to half cell measurements indicating dangerously positive potentials were revealed in only one spot. The measurements at different points in the area of the potential of the cable sheath to a half cell over the cable gave adequate information for the adjustment of the cathodic protection system. The surface gradient measurements proved valuable in locating a discharge of current and in accounting for an extremely high failure rate in the area.
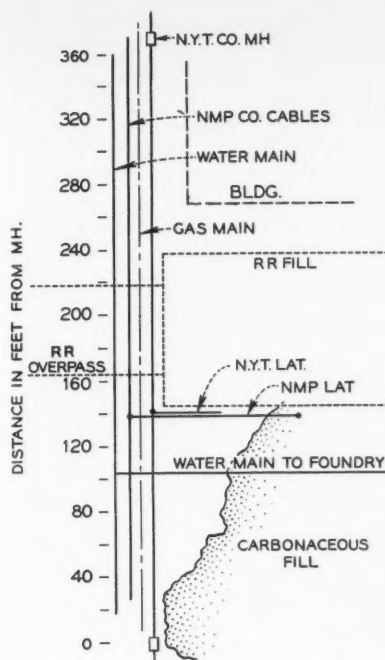
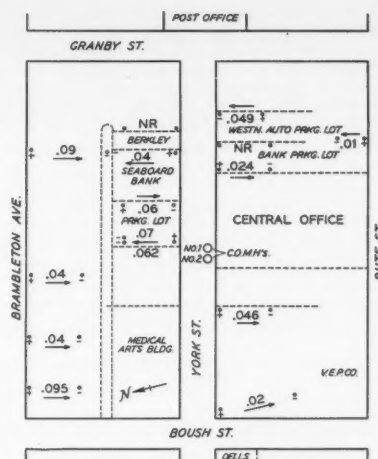Figure 16—Plan view of area surrounding manhole section.
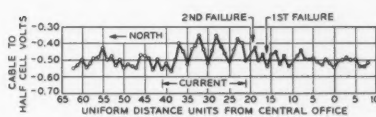

Figure 17—Surface potential gradient survey.

Figure 18—Cable to half cell survey.

Figure 19—Null bridge measurement of structure to half cell potential.

TABLE 1—Null Bridge Measurements

Protection Current in MA	Potential in Volts to CuCuSO₄ Electrode at Indicated Distance from Manhole 288								
	226 Ft.	292 Ft.	300 Ft.	344 Ft.	400 Ft.	415 Ft.	427 Ft.	437 Ft.	466 Ft.
114	—.510	.....	—.540	.....	—.560	—.600	—.492	—.510	—.531
360	—.600	—.552	—.660	—.504	.....	.....	.....	—.590	—.605
520	.....	.....	.....	.....	.....	.....	.....	.....	—.680
700	.....	.....	.....	.....	.....	.....	.....	.....	—.728

TABLE 2—Voltage Readings With Rectifiers On and Off

Measurement Number	Rectifiers	Volts Potential			Half Cell Location with Respect to Cable	
		Null Bridge	Cable to Half Cell			
			Near	Far	Near	Far
1	Off	—.50	—.44	—.43	50'	70'
2	On	—.82	—.73	—.74	50'	70'
3	Off	—.49	—.43	—.43	50'	70'
4	On	—.79	—.71	—.71	50'	70'
5	Off	—.51	—.52	—.52	30'	45'
6	On	—.79	—.79	—.80	30'	45'
7	Off	—.44	—.39	—.40	50'	70'
8	On	—.73	—.69	—.70	50'	70'
9	Off	—.46	—.45	—.47	Curb	Building Line
10	On	—.71	—.71	—.77	Curb	Building Line
11	Off	—.53	—.52	—.70	M.H.	5'
12	On	—.58	—.58	—.74	M.H.	5'

The fourth example gives the kind of data ordinarily obtained from a routine survey. Unless a highly positive area is encountered to indicate stray current, the data are somewhat inconclusive. The corrosion in this case and also in the first example might have been due entirely to small local cells but in view of the variations in potential along the length of the cables, this is not likely. A more detailed study with measure-ments of cable to surface half cell might have confirmed the opinion that the corrosion resulted from long cells.

Conclusions

Potential measurements will not re-veal small cell corrosion and, individ-ually, may not distinguish between a passive and an active state of the lead sheath surface. A zone of uncertainty lies between a potential of —0.40 volt

and —0.62 where individual measure-ments are made of the potential of a lead sheath to a copper sulfate half cell. When a series of measurements are made at regular intervals along a cable between it and a reference electrode in contact with the earth or a duct slug, changes in the potential usually can be interpreted.

Lateral potential gradient measure-ments are useful in detecting areas where the cable is either receiving or discharging current. They should be used in conjunction with measurements along the axis of the cable.

Sheath current measurements are a useful adjunct to potential measure-ments and in some circumstances are the only type of measurement that can be employed. They are useful in deter-mining if cathodic protection current reaches a particular cable in a subway containing multiple ducts and cables. Measurements of the current entering and leaving a section will indicate whether the cable is receiving or dis-charging current. They are useless in cases of short cell corrosion. Usually current from a cable to a slug in a duct indicates current discharging from the cable into the earth; there are situations, however, where the current would be returning to the cable through the earth from the slug due to galvanic effects.

Resistivity measurements, while of secondary importance, are useful in re-vealing wet spots or variations in the soil. Resistance measurements between the cable sheath and a foreign struc-ture are employed to determine the coupling between the two and aid in setting up proper bonding if interfer-ence is encountered. Measurements in-dicating low resistance between a duct slug and the cable grid often indicate points of expected corrosion and aid in the interpretation of a duct survey.

Appendix 1—Null Bridge Potential Measurements

The null bridge as developed by Pear-son, Hadley and Logan[3] is useful in making potential measurements of cable-to-reference electrodes in soil, and in determining the current required for cathodic protection. It is reproduced here in Figure 19. It will eliminate the component of IR drop that is in the common circuit and is produced by cur-

rent through the earth between the far electrode and the cable. The null bridge may reduce the effect of other components of IR drop but cannot eliminate them. For instance, in Figure 19a, the bridge can be balanced so that the ratio of R_1 to R_2 is equal to the ratio of R_4 to R_3 and E_1 will be equal to E_2 when the galvanometer reads zero. This is achieved by tapping the key and adjusting the ratio of R_1 to R_2 until no change is produced in the deflection of the galvanometer G for changes in current from I to I + ΔI. Then the potentiometer voltmeter is adjusted to give a zero reading of G. The voltmeter V will indicate the value of E_2.

If a local field exists in one section of the circuit as in b or c, the potential required to bring the galvanometer in series with the near half cell to zero will be greater in b and lesser in c than the value of E_2. However, the balance of the bridge to give no change in the deflection of the galvanometer as the current is changed from I to ΔI is independent of the local field. Usually the potential of E_1 required to bring the galvanometer to zero while in error by the vector magnitude of the local fields in series with E_2 and R_3 or R_4, is a more nearly correct value than if R_3I had not been balanced out by the bridge circuit. The presence of these local fields can

be discovered under some conditions by moving the location of the near and far electrodes or by making surface potential gradient measurements as in Example 2.

References
1. Scott Ewing. Am. Gas. Assn. Proceedings, 1939, pages 624 to 640 inclusive.
2. L. J. Gorman. *Corrosion*, 1, 163-77 (1945).
3. Kirk H. Logan, et al. *Petroleum Engineer*, 15, 168 (1943) Ref. Ann.
4. O. C. Mudd. *Oil and Gas Journal*, May 14, 1942, page 55. *Corrosion*, 1, No. 4, 192-218 (1945); Ibid, 2, No. 1, 25-58 (1946).
5. D. R. Werner. *Corrosion*, 12, 376t (1956) Aug.
6. D. R. Werner. Report of Technical Practices Committee, T-4B National Association of Corrosion Engineers, March 13, 1956.
7. J. M. Fouts and C. W. Bergerson. *Corrosion*, 13, 12t (1957) Jan.

Any discussions of this article not published above will appear in the June, 1958 issue

---

TECHNICAL PAPERS ON CORROSION WELCOMED

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Corrosion of Zinc
By Differential Aeration*

By G. BIANCHI

Introduction

EXTENSIVE INVESTIGATIONS into the question of corrosion by differential aeration have been made at the Cambridge University research laboratories. Despite the progress made, certain aspects of the problem have not been sufficiently clarified, perhaps because of the rather simplified methods generally employed for the study of these phenomena. In the Evans cell, for example, one compartment contains the solution saturated with oxygen, whereas the other holds the de-aerated solution. In practice, differences in degree of aeration on different zones of the metal surfaces vary continuously and concentration of oxygen at the least aerated zones is not always equal to zero. Furthermore, it is necessary to take into account the phenomena which take place during earlier phases of the process, before the actual final stationary conditions are established, as well as the phenomena connected with the variation in the corrosive medium resulting from the corrosion process itself. Extended analysis reveals how the phenomena of local corrosion on "cathodic" and "anodic" areas superimpose themselves on the corrosion process due to differential aeration.[1] For these reasons, it is felt that experimental research based on new criteria should be of some interest.

Material selected for this study consists of zinc in solutions of sodium chloride. For such a system, there already exist the experiments of Evans and his collaborators[2] and the research of Feitknecht and his collaborators[3] on the nature and structure of corrosion products. Furthermore, zinc being amphoteric in nature and presenting only one state of oxidation, serves particularly well for the scope of this research.

Experimental

The test arrangement shown in Figure 1 was used in this investigation. Difference in aeration is established between the metallic portion of the specimen near the water level and its lower portion. The smaller the thickness of the stationary solution in relation to its height, the more pronounced will be this difference of aeration.

Zinc plate "A" was partially immersed in a solution which was contained in an ebonite box of rectangular cross section. A groove at the bottom of the container and two "ears" at the upper end of the zinc plate served to fix it in a vertical position. The two side edges of the plate were kept at a distance of one millimeter (equal to the specimen thickness)
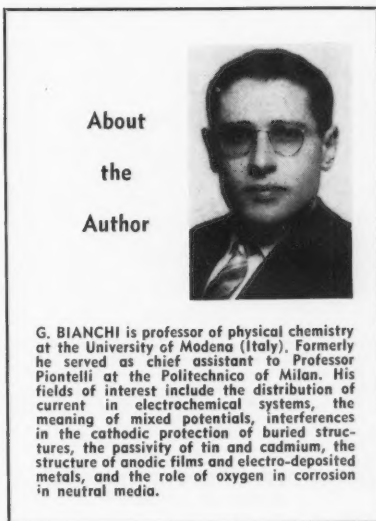
About the Author

G. BIANCHI is professor of physical chemistry at the University of Modena (Italy). Formerly he served as chief assistant to Professor Piontelli at the Politecnico of Milan. His fields of interest include the distribution of current in electrochemical systems, the meaning of mixed potentials, interferences in the cathodic protection of buried structures, the passivity of tin and cadmium, the structure of anodic films and electro-deposited metals, and the role of oxygen in corrosion in neutral media.

from walls of the container. This was done in order to avoid secondary phenomena of differential aeration. In addition, the box contained two sieves of glass "B," which could be placed in positions indicated by arrows in the figure. Purpose of this was to realize the various ratios γ between the thickness of solution next to the plate and height of solution. The latter was always kept constant at 80 mm.

The box was covered with a glass plate and was provided with two holes ("D") for the entrance of gas and four others ("E") for its exit. In this manner the formation of dead pockets was avoided. The ebonite box was immersed in a vessel full of water and a thin layer of paraffin oil was spread at the surface to prevent evaporation. The entire assembly was then placed in a thermostatic chamber, having very low thermal inertia and continued circulation of air (temperature control: ±0.2 degrees C). The thermal inertia of mass water contained in the outer vessel was sufficiently high to nullify the temperature variations in the air thermostatic chamber, thus enabling very high temperature control of the solution. In this manner the thermal convection currents, which could be dangerous in experiments of this nature, were eliminated.

Gases which were to be circulated in the apparatus were first purified (nitrogen with alkaline pyrogallol solution; air with caustic potash solution) and later saturated by bubbling through a solution similar to that used for the test. The rate of the gas flow was adjusted to 150 cc/minute. Tests have been

Abstract

Tests were made to study the differential aeration corrosion of zinc in molar NaCl solutions under varying conditions of aeration, pH, and length of test time. Test results led to the conclusion that formation of differential aeration macrocells is due to passivity of zinc on the zones of the specimen where cathodic reduction of oxygen takes place, and that the principal process of corrosion is accompanied by local corrosion processes at the cathodic and anodic areas of the macrocell. With buffered solutions which do not permit the passivation of zinc, distribution of corrosion changes radically, a localized attack taking place at the water level line where the oxygen flux is at a maximum.   3.6.2

made with zinc plates of two different compositions. The first specimen was a zinc plate obtained by the process of shaving from the fusion cast plate. Its composition was as follows: Fe—0.01 percent, Pb—0.05 percent, Cd—0.004 percent, Cu—0.001 percent, Ni—0.0005 percent.

The second zinc plate was obtained by rolling. It had the following composition: Fe—0.007 percent, Pb—0.009 percent, Cd—0.0008 percent, Cu—0.001 percent, Ni—0.0005 percent.

Before the test, the plate was pickled for ten minutes in cold 7.4 percent HCl, washed and dried. After weighing, the plate was kept in a desiccator for a few hours. Meanwhile the solution to be used for the test was de-aerated by bubbling through it pure nitrogen. After the specimen was mounted the glass cover was sealed with paraffin wax and the required gas (air, oxygen or nitrogen) was circulated for a set period. At the end of the test the plate was photographed and later treated with a cold solution of ammonium chloride and ammonia to dislodge the corrosion products. It was then washed, dried and weighed to obtain the loss in weight ΔP. On a portion of solution, pH determination was made. Except when stated otherwise, all tests were made at 20 C.

It has been found that corrosion depends on the ratio γ between the height H (which was kept constant) and thickness S of the solution (Figure 2). This was determined with a zinc plate of the
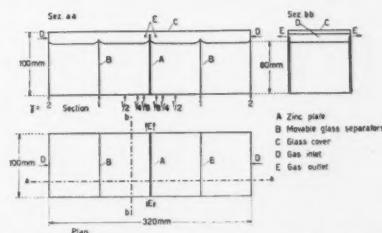
Figure 1—Experimental arrangement for differential aeration corrosion tests. The glass plates "B" can be displaced to realize different values of γ.
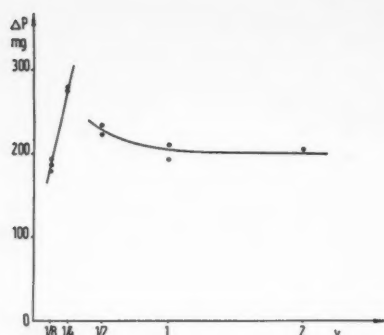
Figure 2—Results of corrosion tests in purified air as a function of γ. Duration of tests was 48 hours.

Figure 4—Influence of test duration on the rate of corrosion. Air was circulated with $\gamma = \frac{1}{4}$.
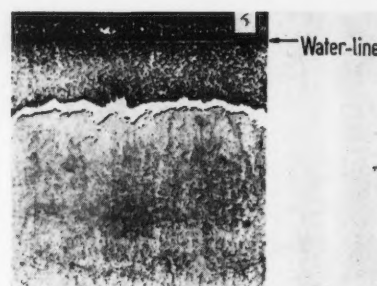

Figure 6—Appearance of zinc specimens at the end of test. The upper cathodic zone is separated from the lower anodic zone by a band of corrosion products. Air was circulated with $\gamma = 2$. The initial pH of the solution was 5.6 and duration of test was 48 hours.


Figure 3—Result of corrosion tests in oxygen as a function of γ. Duration of tests was 21 hours.

Figure 5—Influence of initial pH of the solution on the progress of corrosion phenomenon. Air was circulated with $\gamma = \frac{1}{4}$.

Figure 7—Corrosion of zinc in the M-NaCl + 0.5M-H$_3$BO$_3$ solution at pH 3.9. Air was circulated with $\gamma = \frac{1}{4}$.

TABLE 1—Weight Loss of Pickled Zinc Specimens in NaCl

Duration of Test, (in Hours)	LOSS IN WEIGHT $\triangle$P (IN MG)		
	Cathodic Zone	Anodic Zone	Total
17	19,7	81,1	100,8
24,5	27,2	121,7	148,9
40	38,8	200,0	238,8
102	67,1	352,0	419,1

NOTE: Temperature was 20C and $\gamma = \frac{1}{4}$. Initial pH of the M – NaCl Solution was 6.4.

first type placed in molar sodium chloride solution for a fixed period of time where there was free circulation of air. When the differences of aeration are pronounced, corrosion increases with increase in γ, but then it starts decreasing, finally reaching a value the magnitude of which is independent of γ.

Similar experiments have been conducted in an atmosphere of pure oxygen (Figure 3) for 21 hours' duration and the course of the phenomenon has remained unaltered. For the same value of γ, corrosion of zinc plate increases in linear fashion with increase in the duration of the test. It is only after many hours that the velocity of corrosion decreases (Figure 4). This occurs when the pH of the solution, which in the beginning was increasing gradually, becomes steady at a value of 9. It also will be observed that the period after which corrosion process slows down is related to initial pH of the solution (Figure 5).

Appearance of the zinc plate at the end of the test is shown in Figure 6. At the water level there is a strip that has not corroded (cathodic zone). This strip is separated from the zones further down, where the metal is corroded and covered with a very thin film of corrosion products. Such type of corrosion is well known and has been interpreted as due to more aerated parts becoming cathodic and less aerated parts becoming anodic.

If stirring is resorted to during the test (so that the conditions of differ-

ential aeration are destroyed) it is observed that the zinc plate experiences only slight corrosion. A very thin and uniform film of corrosion products can be observed on its surface.

Tests were conducted to make an individual study of corrosion occurring on "cathodic" and "anodic" zones of the zinc plate. This was done with the same arrangement shown in Figure 1 and in molar solutions of sodium chloride (initial pH = 6.4) at 20 C in an airstream with $\gamma = \frac{1}{4}$, but using instead a plate of second type zinc. A zinc plate was divided into two parts by a cut 5 mm below the water line and the two parts were placed in the electrolyte vertically one above the other, in electrical contact with each other. The results obtained are given in Table 1. From the data obtained, it will be seen that corrosion has not been confined to the "anodic" zone alone but also has something to do with the "cathodic" zone (18 mg/24 hours).

Herzog and Chaudron[4] have observed that the voltage of a differential aeration pile set up at iron electrodes becomes zero if buffered solutions (citrates, borates, etc.) are used. The matter has
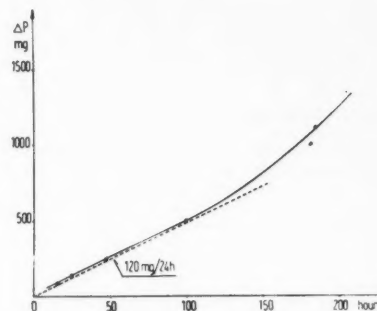
been taken up again for zinc, using the experimental arrangement indicated in Figure 1. The rolled second type zinc plate was used in a current of air at 20 C with $\gamma = \frac{1}{4}$.

Use of a solution of composition M-NaCl + 0.5 M-H$_3$BO$_3$ where pH was 3.9 indicated that the rate of corrosion was more or less the same as that observed with a solution of NaCl alone, but that it had no tendency to diminish over longer test periods. Results obtained are given in Figure 7.

Appearance of the specimens after the test (Figure 8) was very different from that obtained in the previous cases. Corrosion was localized at the water level with the formation of a track; corrosion products were formed only immediately below the water level and became hard and granular in appearance (Figure 9).

Similar results have been obtained with a solution of M-NaCl + 0.5 M-KH$_2$PO$_4$ + NaOH having pH adjusted to 6.4. Weight losses obtained have been plotted in Figure 10 and the curve shows diminution in the rate of corrosion at longer test periods. This can be explained by considering that the buffering capacity of solution when using phosphate is smaller than that obtained with boric acid.

The appearance of specimens is shown in Figure 11. Localization of corrosion on the water level and formation of corrosion products adherent to the metal over the entire plate are observed. In Figure 12 is plotted loss in weight obtained on working with a solution M-NaCl + M-NaOH, from which one concludes that the rate of corrosion is
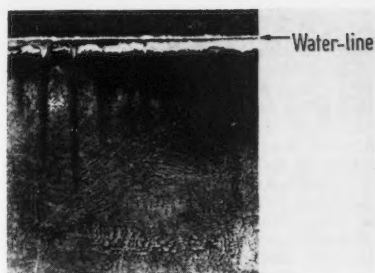
Figure 8—Appearance of the zinc specimen at the end of the corrosion trial in solution of M-NaCl + 0.5M-H₃BO₃. Duration of test was 185 hours.
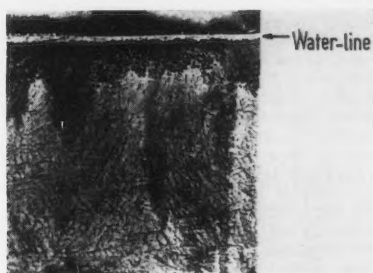
Figure 11—Appearance of the specimen after the test in solution buffered with the phosphate. Duration of test was 30 hours.
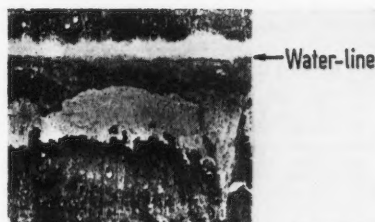
Figure 9—Magnified view showing corrosion at the water level of the specimen of Figure 8. 3X.

Figure 12—Corrosion of zinc in solution of M-NaCl + M-NaOH with circulation of air and $\gamma = \frac{1}{4}$.

Figure 13—Corrosion of zinc in solution of M-NaCl + M-NaOH with circulation of nitrogen and $\gamma = \frac{1}{4}$.
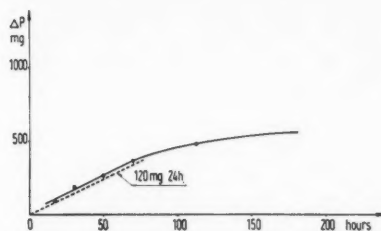
Figure 10—Corrosion of zinc in solution of M-NaCl + 0.05M-KH₂PO₄ + NaOH, initially adjusted at pH 6.4. Air was circulated with $\gamma = \frac{1}{4}$.

Figure 14—Corrosion at the water level observed in solution of M-NaCl + M-NaOH with circulation of air, after a test of 210 hours. 3X.

Figure 15—Section of the zinc plate of previous figure. Localization of the corrosion at the water level was observed.

greater than that observed in previous cases. This is attributed to the ability of zinc to get corroded in strongly alkaline solutions even in absence of oxygen. Overall corrosion, therefore, results from superimposition of the corrosion process due to oxygen reduction on the corrosion process accompanied by hydrogen evolution. The latter process has been isolated and investigated individually by circulating pure nitrogen gas in the cell. The results obtained (see Figure 13) prove that the corrosion rate due to reduction of oxygen is comparable with that observed in previous cases. (Corrosion rate due only to reduction of oxygen is equal to 200-62 mg/24 hours (i.e., 138 mg/24 hours); the values obtained previously were 126, 120 and 120 mg/24 hours in the experiments of Figure 4, 5, 7 and 10 respectively). The increased buffering capacity of the solution used manifests itself into the constancy of corrosion over long test periods. The specimens were completely free of corrosion products with a very strong localization of attack at the water level, as illustrated in Figure 14. Figure 15 is the section of the zinc plate and shows prominently the localization of corrosion.

Discussion of Experimental Results

In differential aeration corrosion of zinc, the anodic process of metal dissolution:
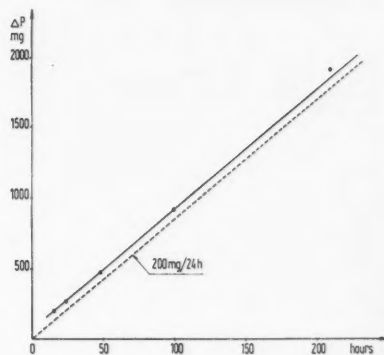
$$Zn \rightarrow Zn^{++} + 2e$$
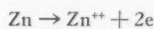
is compensated by the cathodic process of oxygen reduction:

$$\tfrac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^-$$
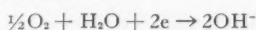
corresponding to the production of OH⁻ ions. The OH⁻ ions diffusing through the solution cause an increase in pH till it reaches the value which corresponds, for that particular concentration of zinc ions, to that at which precipitation of zinc hydroxide occurs. If cathodic and anodic areas are far removed from each other (macroelements), diffusion of Zn⁺⁺ ions from anodic areas and of OH⁻ ions from cathodic areas leads to precipitation of corrosion products on the line of demarcation between cathodic and anodic areas (Figure 6). In cases where the anodic and cathodic areas are very small and are closely mixed up amongst themselves, precipitation of corrosion products takes place in immediate contact with the metal surface; a layer of corrosion products is formed thereby, which exercises protective action. This protection generally is not complete, the layer being porous. Normally the differential aeration corrosion process is under the cathodic control of oxygen diffusion. But if a protective layer of corrosion products is formed on the anodic areas, the corrosion process is under anodic control and becomes independent of the oxygen diffusion process. In one case the mixed potential must be close to the value for the dissolution potential of the metal; in the other case it must become more noble and closer to the potential corresponding to the cathodic process.

Having thus recalled briefly the phenomena that take place on cathodic and anodic areas and in the body of the solution, it will be possible to interpret in the following manner the phenomena of differential aeration corrosion of zinc when the solution is initially free of oxygen.
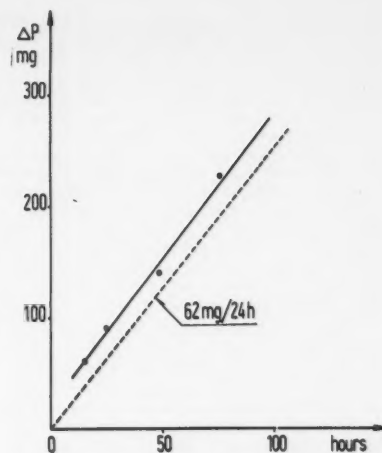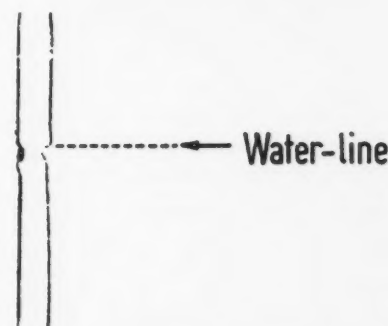
Oxygen, diffusing in the solution, first reaches the metallic specimen surface at the nearest points of the water level and gives rise to a local process of corrosion by the formation of micro galvanic cells, where Zn⁺⁺ and OH⁻ ions are produced. The localized increase in pH leads to the formation of a protective layer of corrosion products and hence to passivation of zinc at the water level. While the cathodic process continues to proceed in such zones that correspond to the maximum flux of oxygen, the process of

zinc dissolution is gradually shifted to the lower parts of the specimen where oxygen flux is so small that increase in pH and passivation of zinc cannot take place. If the conditions of differential aeration are severe, passivation of zinc is confined only to the zones nearest to the water level and corrosion proceeds on the lower parts with the formation of a macro differential aeration cell, as is satisfied under the experimental conditions of Figures 2 and 3 when $\gamma = \frac{1}{8}$ and $\gamma = \frac{1}{4}$. The corrosion process is hence under oxygen diffusion control and initially varies with a linear function of time (Figure 4).

The corrosion intensity increases with the increase in oxygen flux, as it happens on passing from $\gamma = \frac{1}{8}$ to $\gamma = \frac{1}{4}$. The OH⁻ ions formed in reduction of oxygen on cathodic areas manage to reach the anodic areas (whether by diffusion or by convection currents in body of the solution) and lead to passivation. The velocity of the corrosion process therefore falls and the control of oxygen diffusion process on it becomes less important. The interval after which this phenomenon comes into play depends on the initial pH of the solution (Figure 5).

If the condition of differential aeration is mild, the amount of oxygen ar-riving at even more deeply immersed parts of the plate is sufficient to lead to passivation of the entire specimen. The corrosion process is governed by the anodic control and its velocity becomes lower than what it should be if it were under oxygen diffusion control. This means that only a part of available oxygen is reduced, whereas the remaining part of it just accumulates, saturating the solution. Under these conditions, intensity of corrosion process becomes independent of the geometrical conditions which determine the oxygen flux distribution (Figures 2 and 3 for $\gamma = \frac{1}{2}$, 1 and 2).

Hence it follows that the following phenomena overlap on the phenomena of corrosion arising from macro-cells of differential aeration:

1. Corrosion due to local micro-cells at the water level. This is intense in the initial stages, but slows down later due to local passivation of the metal. It can become intense again when accumulation of OH⁻ ions becomes large enough to permit zinc corrosion by zincate formation, or when buffered solutions are used, not permitting the passivation of zinc.

2. Corrosion due to micro-cells in the less aerated zones of the specimen.

Conclusions

In conclusion, formation of macro-cells of differential aeration is connected with passivation of zinc on the more aerated zones. The differential aeration corrosion cannot exist without passivation of the more aerated zones of the metal. If buffered solutions are used ,so that pH is outside the range corresponding to that causing the passivation of zinc, the formation of anodic and cathodic areas constituting differential aeration macrocells is, actually, not observed. Corrosion takes place due to microcells and their distribution coincides with that of the oxygen flux on the metal surface (localized corrosion at the water line, see Figure 15). In this last case, velocity of the corrosion process comes again under the control of oxygen diffusion process in the solution.

References

1. G. Bianchi. *Metall. Ital.*, **45**, 123 and 323 (1953); G. Bianchi and R. Aletti, *Metall. Ital.*, **46**, 347 (1954).
2. Borgmann and Evans. *Trans. Electrochem. Soc.*, **65**, 249 (1934); U. R. Evans. *J. Iron Steel Inst.*, **141**, 221 (1940).
3. W. Feitknecht. *Metaux et Corrosion*, **22**, 192 (1947); W. Feitknecht. *Werkstoffe u. Korrosion*, **6**, 15 (1955).
4. E. Herzog and G. Chaudron. *Comp. Rend.*, **192**, 836 (1931).

The Mechanism of Stress Corrosion Of Austenitic Stainless Steels In Hot Aqueous Chloride Solutions*

By K. W. LEU* and J. N. HELLE*

Introduction

INCREASED use of corrosion resistant materials has made possible the mitigation or elimination of a number of corrosion problems in the oil and chemical industries. Despite this general progress, problems involving stress corrosion attack seem to have become more and more troublesome.

Austenitic stainless steels are among the alloys known to be subject to stress corrosion, failures having been reported in such varying media as high-conductivity water[1] and 100 percent caustic soda.[2] The numerous publications which have appeared in recent years give a good survey of the media in which austenitic stainless steels[1-9] may undergo this type of attack as well as the order of tensile stresses necessary to cause such attack.[1, 9-12] In these accounts, however, there is great divergence of opinion regarding the mechanism of this type of corrosion.[9, 14, 15] None of the theories put forward can explain all the facts observed in actual service and in the laboratory. In actual service it has not proved possible as yet to find suitable means for combating this type of attack, other than by complete stress-relieving of the material and by keeping the stresses at a very low level. Nor has it been possible to establish a relationship between service performance and results obtained in laboratory experiments.

As practical experience has shown, the chloride ion is one of the principal offenders in causing stress corrosion in austenitic stainless steels. If only the chloride ion in aqueous solutions were the active agent, all chloride solutions would behave in the same way and, for a certain type of steel at a certain magnitude of applied stress, only the concentration and the temperature would then determine the time of failure. However, not all aqueous chloride solutions give rise to stress corrosion to the same extent. In solutions where stainless steels are very resistant to corrosive attack ($MgCl_2$, $CaCl_2$, $ZnCl_2$), tensile stresses very soon lead to stress corrosion. In solutions where pitting normally occurs (NaCl, KCl, NH_4Cl) the phenomenon can be observed only after very long exposure times; in solutions causing a heavy attack ($CrCl_2$ $FeCl_3$, $HgCl_2$) no stress corrosion is experienced. Furthermore it is known that the addition of oxidizing compounds to

chloride solutions may promote this type of attack. The latter facts suggest that for the ocurrence of stress corrosion in austenitic stainless steels the chemical and mechanical behavior of the passivating film are factors of importance.

The present paper presents some results that have so far been obtained in an investigation on the mechanism of stress corrosion of austenitic stainless steels in hot aqueous chloride solutions.

Method of Investigation

In choosing the steels for the investigation, special attention was paid to ensuring that they were of normal composition and that in the annealed and quenched condition no α- and δ-ferrite was present. The chemical compositions of these steels, determined by standard methods, are tabulated in Table 1.

Before testing, all specimens (dimensions: 120 x 8 x 2 mm) were stress-relieved by annealing for 30 minutes at 900 C, followed by cooling in still air. Next, the specimens were pickled to remove the oxide film and polished. Polishing was done electrolytically in order to obtain an undeformed and reproducible surface. This was carried out in a solution consisting of 25 gm of CrO_3, 133 ml of acetic anhydride and 7 ml of H_2O. With a current of 0.5 amp/sq cm at a potential of about 60 v a satisfactory polish and reproducibility of surface was realized. After polishing, the specimens were washed thoroughly and then electrolytically etched in a 10 percent oxalic acid solution to reveal the structure. The etching time was about 1-1½ minutes. The specimens were then passivated in air for the formation of a protective film. The time of exposure to air depended on the type of experiments to be carried out. Normally, if the passivating treatment is not mentioned, it was one hour in duration in air at room temperature.

The specimens were next mounted in a stainless steel holder (Figure 1), from which they were insulated by small glass rods and in which they could be stressed. The whole assembly was placed in the boiling chloride solution; from time to time the assembly was taken out and examined after washing. The construction of the holder permitted the changes in the metallic structure due to deformation, the initial corrosive attack and the cracks formed under the stresses applied to be studied under the microscope at magnifications up to 1000.

In the first few experiments a normal

Abstract

An investigation into the mechanism of transcrystalline stress corrosion of austenitic stainless steels (18 Cr/8 Ni and 25 Cr/20 Ni) in hot aqueous chloride solutions has shown that this phenomenon must be described as being a process alternating between corrosion and mechanical cracking. Only sharp-edged pits formed by a specific corrosive attack initiate and propagate the mechanical cracking. These pits act as stress raisers; the conditions for notch brittleness of the materials involved are produced, so that mechanical cracking occurs, which is of a brittle nature.

At high stresses small pits occurring either at the slip bands or at the grain boundaries may cause cracking, whereas at low applied stresses, only longish pits formed at the slip bands initiate it.

The investigation proves that the initial corrosive attack is dependent primarily on the mechanical and chemical behavior of the passivating film already present on the steel or formed during exposure to the corrosive medium, and only to a minor extent on the structure of the metal itself.

If the type of initial corrosive attack is changed by comparatively small alterations in the composition of the corrosive medium, stress corrosion is either prevented or accelerated. Tests illustrating this observation are discussed.   3.5.8

fine-grained material was used. This material, however, did not reveal sufficient details of the initial attack and the propagation of the cracks to give information of any value on the mechanism of stress corrosion. Moreover, as the cracking was transcrystalline, the initial attack and cracking must have occurred in the grains and not at the grain boundaries. For these reasons, most of the experiments were carried out with material recrystallized at a temperature of 1250-1300 C and slowly cooled.

As corroding agents the following
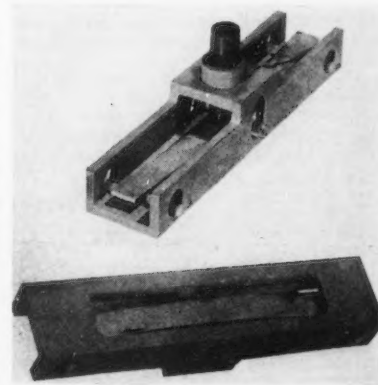
Figure 1—Specimen holder.
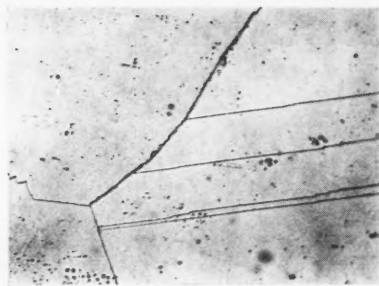
Figure 2—Steel A (AISI 304) recrystallized, polished and etched. Original magnification, 300X; actual magnification after reduction for engraving purposes, 165X.
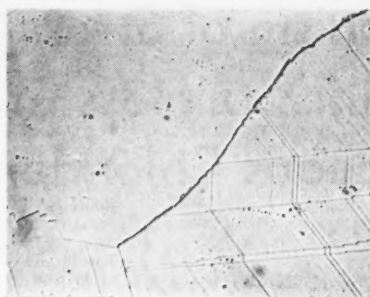
Figure 4—Same specimen pictured in Figure 3 but after 10-minute exposure to boiling MgCl₂ solution. Original magnification, 300X; actual magnification after reduction for engraving purposes, 165X.

Figure 3—Specimen shown in Figure 2 after deformation. Original magnification, 300X; actual magnification after reduction for engraving purposes, 165X.
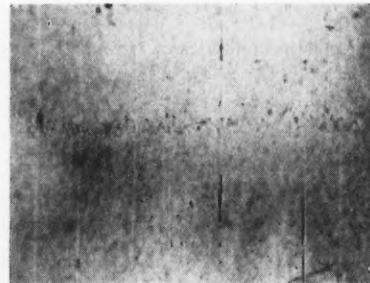
Figure 5—Steel A after passivation in air for 240 hours and short exposure to boiling MgCl₂. Slip bands were attacked. Original magnification, 770X; actual magnification after reduction for engraving purposes, 430X.

Figure 6—Same specimen as pictured in Figure 5 but after a one-hour exposure to boiling MgCl₂ solution. Cracks formed. Original magnification, 600X; actual magnification after reduction for engraving purposes, 440X.

aqueous solutions were employed at their boiling points:

    42% MgCl₂ (chem. pure), and

    6% NaCl + 1.5% Na₂Cr₂O₇ (both a.r. quality).

Each specimen was tested in 300 cc of a fresh solution.

Experimental Results

Initial Corrosion Attack in MgCl₂

Steel A (AISI 304) in the recrystallized condition, after electrolytic polishing, etching and passivation in air for one hour, showed a large even grain size with some twinning and precipitation of carbides at the grain boundaries (Figure 2). After stressing (deflection: 2 mm) a few slip bands were visible (Figure 3). Exposure to the boiling MgCl₂ solution (t = 154 C) for 10 minutes resulted in more slip bands (Figure 4). This phenomenon is due to the decrease in the yield strength, which for this steel is in the order of 22 kg/sq mm at room temperature, and about 18 kg/sq mm at 150 C.

The amount of slip bands formed which are observable with the normal microscope depends on the thickness of the oxide film and its mechanical properties. The same steel showed a some-

what different picture in this respect after the normal pretreatment and after passivating in air for 240 hours. Only a few slip lines could be observed in this case; they were attacked by the corroding agent (Figure 5). After exposure to MgCl₂ for one hour, fine cracks had developed, originating in those areas on the slip bands which had been heavily attacked. The cracks formed were all in a plane perpendicular to the orientation of the highest tensile stresses and showed no relation whatsoever to the structure of the metal (Figure 6).

Various experiments carried out with recrystallized steels A (AISI 304), B (AISI 317) and C (AISI 347) stressed just above the yield point at room temperature invariably showed the same phenomena: pitting alternating with very fine cracks, the pattern resembling a pearl necklace. This suggested that a pit is initially formed by corrosion; the pit then acts as a stress raiser and so initiates the mechanical formation of a crack. Near the tips of the cracks, corrosion again starts and results in a pit. Thus a new notch is formed at which the stresses are enhanced and consequently the crack can propagate mechanically. Figure 7 shows how this occurs.*

After mechanical cracking, corrosion starts along the cracks, the freshly exposed material not being protected by an oxide film. This process is very slow as compared with the mechanical cracking of the steel. However, it starts immediately after cracking and therefore it is very difficult to find specimens in which no secondary attack has taken place. Along the newly formed pits, slip of the material can sometimes be observed (Figure 8).

In order to confirm the hypothesis that stress corrosion must be a process alternating between corrosion and mechanical cracking, experiments were carried out with recrystallized steel B (AISI 317). The material was stressed just above the yield point at room temperature and continuously examined microscopically. After 48 hours' exposure to boiling MgCl₂, corrosive attack on the slip bands resulting in pitting was observed. These pits were comparatively large and rotund in shape (Figure 9.) They show a fine structure and the cracks formed have their origin in the fine "surface cracks" visible.

Figure 10 shows another area of this specimen. Besides various pits the tip of a crack already formed is visible in the upper part of this micrograph. After further exposure for ½ hour the crack had developed further (Figure 11) by the formation of a new pit at its tip, and by the further mechanism already described. Along the crack formed, no slip of the material can be observed. Mechanical deformation of the specimen did not cause the crack to progress; it only became wider and at its tip the material was heavily deformed by slip (Figure 12).

By means of etching or a corrosive reaction large roundish pits were produced on polished surfaces. Then the specimens were exposed to the boiling MgCl₂ solution. The cracks formed always had their origin in the newly formed pits at

TABLE 1—Chemical Composition of Steels

Designation	AISI Type	Chemical Composition, percent by Weight							
		C	Cr	Ni	Mo	Si	Mn	Ti	Nb/Cb
A.	304	0.07	17.9	9.2	. . .	0.61	0.73	. . .	. . .
B.	317	0.09	18.5	13.4	3.68	0.50	1.80	. . .	. . .
C.	347	0.06	18.2	11.5	0.14	1.10	2.00	0.12	1.1
D.	310	0.05	24.9	19.0	. . .	0.36	.1.83	. . .	. . .

* For reasons of clarity the specimen was polished slightly after exposure to remove the corrosion products precipitated on the surface. The slip bands therefore are not seen.
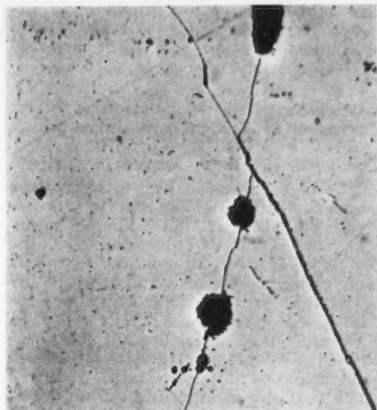
Figure 7—Pitting alternating with cracks mechanically formed. Original magnification, 400X; actual magnification after reduction for engraving purposes, 320X.
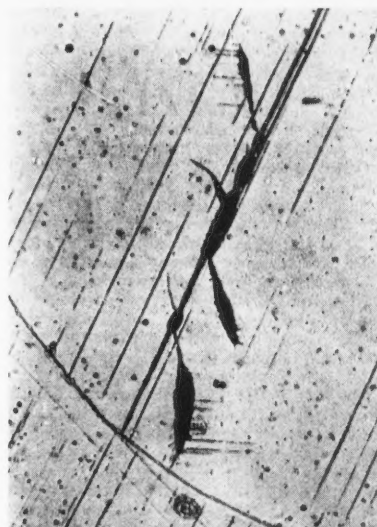
Figure 8—Slip along pits formed at the tips of cracks. Original magnification, 550X; actual magnification after reduction for engraving purposes, 305X.

Figure 9—Fine structure of a pit. Original magnification, 450X; actual magnifications after reproduction for engraving purposes, 600X.

Figure 10—Pit and tip of a crack. Original magnification, 300X; actual magnification after reduction for engraving purposes, 210X.

Figure 11—Specimen shown in Figure 10 after further exposure. Note propagation of the crack. No deformation is observable along the crack. Original magnification, 500X; actual magnification after reduction for engraving purposes, 360X.

Figure 12—Specimen shown in Figures 10 and 11 after further deformation. Note slip at the pit of the crack. Original magnification, 365X; actual magnification after reduction for engraving purposes, 220X.

the slip bands and not in the large roundish ones.

These results indicate that the shape of the pits is of major importance. Very fine, sharp-edged pits appear to initiate cracking of the material whereas roundish pits with no substructure seem to be much less likely to do so. In particular, elongated and deep pits are dangerous from this point of view.

Figure 13 shows the cracks formed in recrystallized steel B (AISI 317) under high stresses (deflection: 4 mm). The first attack (pitting) took place at the grain boundaries; the long crack formed, has its origin in this pit. The crack shows branching and curving, two symptoms suggesting that the fracturing process is of a brittle nature. Along this crack again no additional deformation of the material was observed.

It was found also that in the case of high stresses the initial corrosive attack occurs on the slip lines. Steel A (AISI 304) exposed immediately after stressing to the boiling MgCl₂-solution showed cracking after only 15 minutes. The initial attack occurred on the slip bands

and the cracks formed were very fine (Figure 14).

The authors hold the view that the α-ferrite formed by deformation is not responsible for the initial corrosive attack. To test this assumption, experiments were carried out with specimens which after

stressing showed no α-ferrite. Steel A (AISI 304) was stressed at 200 C (deflection: 4 mm) and then immediately exposed to boiling MgCl₂ solution. It may be assumed that at this temperature no α-ferrite (martensite) is formed. The slip bands formed were very numerous owing to the drop in the yield point. The same attack was observed as when deforming this austenitic steel at room temperature (Figure 15).

Tests (deflection: 4 mm) also were carried out with steel D (AISI 310) which is not prone to form α-ferrite upon deformation. The slip bands were heavily attacked and by the resulting pits cracking of the material was initiated. Cracks were observed after four hours on exposure to the boiling solution immediately after stressing (Figure 16).

To confirm the results obtained with recrystallized material, tests were carried out with fine-grained material. No difference in mechanism was observed.

*Tests in Boiling 6 Percent NaCl,
1.5 Percent Na₂Cr₂O₇*

Experiments carried out in a 6 percent NaCl, 1.5 percent Na₂Cr₂O₇ solution confirmed the anticipation that in this medium the mechanism of stress corrosion would be the same as in a boiling magnesium chloride solution.

Figure 13—Steel B exposed under high stresses. Crack formed shows branching and curving. Original magnification, 290X; actual magnification after reduction for engraving purposes, 160X.

The pits initially formed by corrosion were larger and less deep and the cracks formed consequently were shorter. In the pits a corrosion product was precipitated. In these experiments the appearance of a "pearl necklace" again was observed.

Influence of Thickness of Passivating Film

This section describes briefly some results obtained on the physical and chemical behavior of the passivating film and on the influence of small alterations in the chemical composition on stress corrosion of austenitic stainless steels in aqueous chloride solutions. Steel A (AISI 304) which is susceptible to the γ-α-transformation was used for carrying out these experiments.

As regards the number of cracks formed, a difference was observed between specimens passivated in air for one hour, one day and one week. The number of cracks was highest in those specimens which were passivated longest if the specimens were exposed to boiling $MgCl_2$ solutions immediately after stressing.

In order to test the belief that during the process of slip the oxide film on the metallic surface is broken or at least greatly weakened, so that the possibility of a corrosive attack is present, specimens were tested after two types of pretreatment. These were:

(a) Passivation, stressing, further passivation in air, and

(b) Passivation and stressing only.

If the specimens (b) were immediately exposed to boiling $MgCl_2$ solution, they already showed the first cracks after 15 minutes, while the "passivated-stressed-passivated" specimens developed cracks only after about two hours' exposure.

In comparative tests carried out in the $NaCl$-$Na_2Cr_2O_7$ solution a corrosion product was formed on the "passivated-stressed" strips after one minute, whereas on the "passivated-stressed-passivated" specimens this corrosion product formed only after a considerably longer time. The same can be said with respect to the time for cracking.

The influence of the silicon content of the oxide film present on the steel was studied with steels having silicon contents between 0.30 and 3.0 percent.

The specimens tested, exposed immediately after stressing, showed a relationship between the silicon content and the number of cracks formed. An increase in the silicon content resulted in an increase in the number of cracks.

Influence of Reducing Substances

The addition of $SnCl_2$, metallic magnesium or zinc to the boiling $MgCl_2$ solution resulted in the prevention, or at least in a spectacular reduction of stress corrosion. The Mg or Zn added was not in contact with the specimens. After long exposure times no pitting could be observed.

The addition of $SnCl_2$ presumably results in a continuous reduction of the passivating film, while Mg and Zn act as depolarizer, whereby the corrosive attack is changed. Metallic Mg, if added to the $NaCl$-$Na_2Cr_2O_7$ solution, resulted in prevention of stress corrosion. Metallic Zn could not eliminate the formation of initial cracks, although it did prevent their propagation.

Mechanism of Stress Corrosion in Hot Aqueous Chloride Solutions

On the basis of the experimental results obtained the phenomenon of transcrystalline stress corrosion in hot chloride solutions may be said to develop as follows: Stressing of austenitic steels leads to a deformation of the material which results in slip. At the places where slip occurs the oxide film present on the surface can be damaged, so that a corrosive attack at these places is possible. This then results in pitting. These pits act as stress raisers, so that mechanical cracking of the material is initiated. The cracks lie in a plane perpendicular to the highest tensile stress and do not proceed along crystallographic planes. At high stresses small pits are sufficient for initiating cracking; with stresses in the order of the yield point of the material, elongated pits are necessary to cause this phenomenon. If the corrosive attack is of such a nature that sharp-edged pits are not formed, no stress corrosion will occur.

Along the cracks, which are very fine, no deformation takes place. The cracks show curving and branching, particularly so at higher stresses. The length of the cracks depends on the magnitude of tensile stresses the form and the dimension of the pits, the orientation of the crystal or crystals involved, the temperature, etc.

Near the tips of the initial cracks a fresh corrosive attack takes place, probably owing to the development of very fine slip lines in their vicinity or owing to a still unknown factor, resulting in pitting. At these newly formed pits the stresses are enhanced. The further progress is then a process alternating between corrosion (pitting at the tips) and mechanical cracking until the material fails completely.

Discussion of the Mechanism of Stress Corrosion of Austenitic Stainless Steels

The Brittle Fracturing Process

The mechanism of the brittle fracture theoretically is best known in a completely brittle material. This phenomenon, however, is also observed in ductile metals under certain conditions and is then called notch brittleness. It is believed that brittle fracture in otherwise ductile material occurs chiefly when, in a triaxial state of tension, at least one principal stress is tensile in nature. Relaxation of a shear stress across a crack (e.g., by a notch formed mechanically or by corrosion) will result in stress concentration in this surface crack.

It should be emphasized that the micromechanism of fracture is understood only in very special cases and therefore that it is not yet possible to give a quantitative interpretation of the fracturing process in the case of stress corrosion. Factors which are known to be of importance, but whose influence is not yet understood are the surface energy, the hydrostatic pressure in the pits formed, stress distribution in polycrystalline material, phase transformations, etc. Nevertheless some general conclusions with respect to the initiation of the first cracks or their propagation can be drawn. If the rate of the corrosive attack along the slip bands is taken as a constant, it can be said that if the stresses are high, cracks will appear soon, whereas if they are low, cracks will develop only after prolonged exposure. Obviously, if the stresses are not evenly distributed, the time necessary for the first cracks to appear will differ from place to place. Not taking into account the rate of the corrosive attack, it can be concluded that the shape of the pit formed by corrosion is of major importance. As its length is greater and its radius of curvature is smaller, the possibilities of initiating a crack at a certain magnitude of applied stress are greater. It is understandable therefore that not all pits lead to cracking. Roundish pits will not enhance stresses to any marked extent, and thus a crack may be expected to develop there only at very high stresses. Elongated pits with a very small radius of curvature, on the other hand, may suffice to initiate a mechanical crack at a low stress.

In view of the foregoing it also is understandable that in service, owing to an uneven distribution of stresses, there is such a variation in time until failure takes place and that it is very difficult to find a correlation between laboratory experiments and service performance.

The Corrosive Attack

The experimental work has shown that the corrosion starting the process is to a great extent determined by the mechanical and chemical behavior of the passivating film on the surface (formed previously or by the action of the medium) and not to the presence or absence of α-ferrite as postulated by Edeleanu.[8] The initial corrosive attack occurs only at the places where the passivating film is impaired upon deformation. In the authors' opinion there are three main factors which influence the site and the

form of the initial corrosive attack and consequently determine whether or not cracking of the material will be induced: (a) the magnitude of the stresses, (b) the structure of the passivating film and its physical and chemical behavior, and (c) the composition of the aggressive medium.

The magnitude of the stresses and their distribution not only influence the mechanical cracking process in general, but also determine the areas where the initial corrosive attack will occur. It was found that at low applied stresses the initial corrosive attack takes place at only a few spots on the slip bands, whereas at higher stresses this attack occurs in many places both at the slip bands and at the grain boundaries. This variation in initial attack can be explained by the fact that at low applied stresses the slip process takes place only in the grains and not in the nearest vicinity of the grain boundaries. At the latter, owing to the heavily disordered structure, higher stresses are needed to bring about yielding of this material. Therefore, at lower stresses only the film is fractured or its passivating properties are impaired at the slip bands, whereas at high stresses this also occurs at the grain boundaries.

A chemically resistant film which is very brittle will show many defects, even when low stresses are applied. Thus, if the conditions for crack initiation are fulfilled, many such cracks can be observed. On the other hand a film which is ductile and therefore can easily be deformed will cause only a few cracks.

According to Rhodin[13] an amorphous oxide film formed on stainless steel is more ductile than a crystalline one. The difference in the number of cracks formed, between specimens covered with a thin film and with a thicker film is due to the difference in mechanical properties. In general the ductility of films is impaired with increasing thickness.

Apart from the mechanical behavior of the oxide film, its chemical resistance has a great influence on the initial attack, especially as regards rate and type. Passivated metals which show a good resistance against corrosion but which are susceptible to a local corrosive attack by chloride ions, are prone to stress corrosion in solutions containing these ions. It is known, for example, that an amorphous film will afford better chemical protection than a crystalline one. Rhodin[13] showed that in the case of stainless steels it is particularly the silicon content which enhances the resistance against corrosion by chlorides. It can be assumed that silicon impairs the ductility of the film, so that the material then becomes very susceptible to stress corrosion. The results obtained in the present investigation confirm this.

If a passivating film has a low resistance to corrosion, no stress corrosion can be expected, because the attack is then general and not local.

Not all chloride solutions show the same severity in causing stress corrosion. This must be ascribed to differences in pH, resulting from hydrolysis of the salts and to the possibility that certain metallic ions have a more pronounced influence on the polarization or depolarization of the anodic or cathodic reactions than do others. Consequently the initial corrosive attack can show a variation in rate and form.

The presence of other compounds also influences the corrosive attack. Oxidiz-
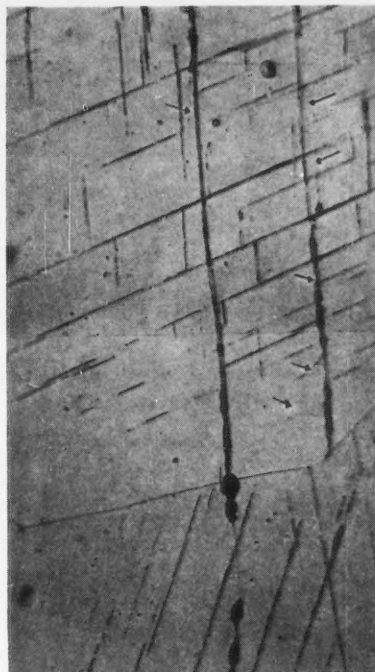
Figure 14—Heavily stressed material. Note attack at the slip bands and cracks formed. Arrows point to crack. Original magnification, 900X; actual magnification after reduction for engraving purposes, 540X.

ing compounds (e.g., $Na_2Cr_2O_7$, H_2O_2, oxygen) which polarize the anodic corrosive reaction, or inhibitors adsorbed at the anodic areas, can counteract the corrosive attack. By the action of these compounds normal pitting can be changed into a very fine pitting. Hence, stress corrosion is promoted, as could be shown with NaCl-solutions. On the other hand, depolarizing substances can change the corrosive attack in such a way that no sharp-edged pits are formed. The same effect is produced by a reducing compound, which continuously reduces the passivating film, so that no pitting can occur.

Acknowledgments

The authors wish to thank the management of the Koninklijke/Shell-Laboratorium, Amsterdam, for permission to publish this paper. They are also indebted to their colleagues for many helpful discussions.

References

1. W. L. Williams and J. F. Eckel. *J. Am. Soc. Naval Engrs.*, **68**, 93-103 (1956).
2. J. J. Heger. *Metal Progr.*, **67**, 109-116 (1955).
3. Symposium on Stress Corrosion Cracking of Metals, ASTM/AIME 1944.
4. H. Nathorst. Welding Research Council Bull., Ser. No. 6, 1-11 (1950).
5. W. G. Renshaw. Allegheny Ludlum Steel Corp. report (1952).
6. H. W. Schmidt, P. J. Gegner, G. Heinemann, C. F. Pogocar and E. H. Wyche. *Corrosion*, 7, 295-302 (1951).
7. J. A. Collins. *Corrosion*, 11, 27-34 (1955).
8. C. Edeleanu. *J. Iron Steel Inst.* (London), 173, 140-146 (1953).
9. H. J. Rocha. Tech. Mitt. Krupp Forschungsber, 5, 1-14 (1942).
10. M. A. Scheil. Symposium on Stress Corrosion Cracking of Metals, ASTM/AIME 1944, 395, 425.
11. J. C. Hodge and J. L. Miller. Trans. Am. Soc. Metals, **28**, 25-67 (1940).

Figure 15—Steel A deformed at 200 C. Note attack at the slip bands and crack formed. Original magnification, 540X; actual magnification after reduction for engraving purposes, 440X.
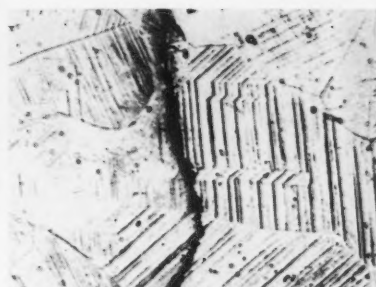
Figure 16—Steel D (AISI 310). Note attack at slip bands and crack formed. Original magnification, 600X; actual magnification after reduction for engraving purposes, 330X.

12. H. R. Copson. Corrosion Handbook (H. H. Uhlig, Editor). John Wiley and Sons, New York, 1948, p. 569.
13. T. F. Rhodin. *Corrosion*, 12, 123t-135t (1956) Mar.
14. T. P. Hoar and J. G. Hines. *J. Iron Steel Inst.* (London), **182**, 124-143 (1956).
15. H. L. Logan and R. J. Sherman. *Welding J.* (N. Y.), **35**, 389S-395S (1956).

DISCUSSION

Questions by Charles P. Dillon, Carbide and Carbon Chemical Company, Texas City, Texas:

1. If the stainless steel is stressed above the yield point, and the stress is multiplied by pitting, why is this apparently a *brittle* fracture?

2. If electrochemical action is entailed in the crack propagation, does not the geometry of the system require that the cathode area be contained within the crack?

Replies by K. W. Leu:

1. In a notch formed mechanically or by corrosion (e. g., pitting) the applied stresses are multiplied and consequently the steel will be further deformed at the root of the notch. If there is no possibility for further yielding of the material, a mechanical crack will be initiated. The nature of the fracture (brittle or ductile) depends on various factors (e. g., the sharpness of the notch, the temperature, etc.).

The appearance of the cracks formed in stainless steel as a result of stress corrosion indicates that they are of brittle

nature. So far, no investigation has been carried out by us into the mechanism of crack initiation and brittle fracturing in stainless steels.

2. We have found that after mechanical cracking corrosion starts along the cracks and that this process is very slow as compared with the cracking process. Therefore it can be assumed that the geometry of the anode/cathode system in and along the crack is not a simple one.

Assuming that electrochemical action is involved in the propagation of the crack, the geometry of the system then requires:

(a) That the cathode area be contained within the crack, or
(b) That anodic passivation of the unstressed fractured sides of the cracks is taking place.

Question by E. H. Phelps, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.:

Is it correct that your proposed mechanism applies only to the extension of cracks on the surface of the metal, and not to propagation of cracks through the metal?

Reply by K. W. Leu:

Indications were that for the propagation of cracks through the metal, the described mechanism also applies. On making cross-sections through specimens, it was observed that in the case of "roundish pits" formed at the root of the crack no propagation of the cracks occurred, whereas in the case of "sharp-edged pits" this could take place.

Any discussions of this article not published above
will appear in the June, 1958 issue

DISCUSSIONS ON TECHNICAL ARTICLES ARE SOLICITED

Discussions on technical articles published in Corrosion will be accepted for review without invitation. Discussions must be constructive, accompanied by full substantiation of fact in the form of tables, graphs or other representative data and be submitted in three typewritten copies.

Authors of discussions are asked to supply one copy of figures suitable for reproduction and will be sent on request a copy of the NACE Outline for the Preparation and Presentation of Papers.

Discussions will be reviewed by the editor of Corrosion and will be sent to the author of the paper discussed for his replies, if any. Publication will be in the Technical Section with full credit to the authors together with replies. Discussions to papers presented at meetings of the association may be submitted in writing at the time of presentation or later by mail to the editorial offices of Corrosion, 1061 M & M Bldg., Houston 2, Texas.
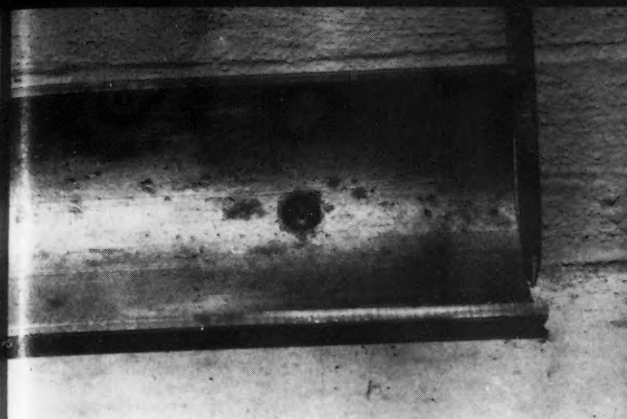
Figure 1—Penetration of new 3/16-inch thick injection string, after 3.5 month exposure. Hydrogen sulfide content of water was 105 mg/liter; temperature was 115 F.

Figure 2—Metal-to-metal chrome plated plunger in service 35 days. Hydrogen sulfide content of water was 1.0 mg/liter coupled with CaCO₃ deposition.

Corrosion Problems in Water Flooding*

By RAY W. AMSTUTZ

Introduction

CORROSION FAILURES are serious matters in water floods because they usually reach a maximum near the economic limit of the flood. Repairs and replacements which would be economically feasible in the early life of a flood become prohibitive near the end. It is essential therefore that the corrosion engineer plan and carry out a preventive program early in the flood life. Such a program will be cheaper in direct costs and it also may provide additional profit for the operator by extending the economic life of the flood.

The pilot flood is the best time to establish the most feasible means of water treatment and corrosion control. Where possible, a closed system is preferred to an open system. In either type, the minimum treatment of water should be applied. Use of corrosion preventive measures is strictly a matter of economics. If it is cheaper to use them than to live with the corrosion, their use is justified. Living with the corrosion creates a possible secondary problem of plugging of the injection wells with products of corrosion. This expense also should be considered when an estimate is made of corrosion costs.

Internal Corrosion Problems

Methods of Detection or Prediction of Corrosion

The seven basic tools or methods of detecting or of predicting corrosion in water flood operations are (1) water analyses, (2) corrosion coupon tests, (3) corrosion probe tests, (4) bacteria tests, (5) membrane filter analyses, (6) review of the corrosion history and (7) examination of existing equipment.

Complete water analyses are the first requirements. The analyses offer some indication of possible corrosive agents and their concentrations may be used as

About the Author

RAY W. AMSTUTZ is with Earlougher Engineering, Tulsa, Oklahoma, where he is in charge of the water laboratory. His duties include supervising water analyses and doing work in water treatment, bacteria and corrosion control. Mr. Amstutz received a BS in petroleum engineering in 1948 from the University of Tulsa. He is a member of AIME and NACE and was registered as a professional engineer in the State of Oklahoma in 1952.

Abstract

The seven basic methods of detecting corrosion in water flood operations are water analyses, corrosion coupon tests, corrosion probe tests, bacteria tests, corrosion probe tests, bacteria tests, membrane filter analyses, review of the corrosion history, and examination of existing equipment. Each of these methods is discussed briefly.

Consideration is given to some of the principal causes of internal corrosion. Methods of controlling such corrosion include inhibitor treatment, aeration, bacteria control, cathodic protection and the use of corrosion resistant materials.

External corrosion problems are discussed briefly with particular attention being paid to buried surface lines and well casing. **4.6.12**

a rough indication of the severity of the expected corrosion.

Results of corrosion coupon tests are excellent for relative comparison. The indicated corrosion rates obtained by corrosion coupon tests usually cannot be applied directly as a measure of the rate of corrosion of the equipment. However, they are of considerable qualitative value and they have some quantitative value when used to evaluate the results of mechanical or chemical changes in the injection system.

Results of corrosion probe tests are similar to those of the coupon tests. The principal advantages of probe installations over the coupon installations are that the probe data can be obtained without interrupting operations and the results can be obtained quicker. Since the required interval of time is much

shorter for probes than for coupons, the probe data often permit detection of changes in the corrosion rate which cannot be found with conventional coupon tests. For example, opening of an injection line with resultant oxygen contamination may increase the corrosion rate for that day to a value of several times the normal corrosion rate. Daily readings of a corrosion probe should reflect this change. A two-week exposure of corrosion coupons may indicate a slightly higher average corrosion rate for the two-week period but the reason for the increase is not readily detected.

Bacteria tests are important for corrosion evaluation principally because of the frequent contamination of flood waters with hydrogen sulfide producing bacteria. The most common, of course, is the sulfate reducer and inhibition of this type bacteria is justified from a corrosion viewpoint.

Membrane filter analyses are an excellent means of obtaining quantitative estimates of the amount of corrosion products present in the injection water.

The most accurate methods available for evaluating corrosion problems consist of reviewing the corrosion history

Figure 3—Internal corrosion accelerated by bacteria activity (inside view).

Figure 4—Internal corrosion accelerated by bacteria acitvity (outside view).

Figure 5—Reduction of corrosion coupon rates and iron content with inhibitor treatment.

high corrosion rate with early failure of the probe. However, this does not occur frequently enough for one to depend upon it for detection of pitting-type corrosion.

All of the above statements concerning hydrogen sulfide attack refer to sulfide which is present in the source water. These same conditions can be duplicated by bacterial activity in a water system. One of the most common evidences of this is the appearance of black iron sulfide in the waters or on the pipe walls in a system where no hydrogen sulfide or iron sulfide is found in the source waters. The iron which combines with the bacteria-produced sulfide may be supplied by ferrous iron from the water or metallic iron from the internal pipe walls. In either case, the presence of the iron sulfide forms the familiar galvanic cell with resultant pitting and accelerated corrosion rates. Figures 3 and 4 show inside and outside views of pit-type corrosion which probably was accelerated by bacteria-produced hydrogen sulfide.[1]

It is possible that sulfate reducing bacteria also play the role of a depolarizer in accelerating corrosion. The corrosion process normally is retarded by formation of a hydrogen layer on the cathode. Since sulfate reducing bacteria have the capacity to use free hydrogen in their biological process of producing hydrogen sulfide, it is possible that they remove the hydrogen film from the cathode thereby permitting accelerated corrosion by depolarization.

Sulfate reducing bacteria live in abundance over much of the earth. They thrive in areas of low oxygen content; however, they are facultative and can exist in an oxygen environment. Sulfate reducing bacteria have been found in tubercles on pipe walls and water mains which transport fresh water carrying a high dissolved oxygen content.[2] The tubercles are formed initially by oxygen corrosion of the pipe but as oxygen is consumed within the tubercle the environment becomes anaerobic thereby permitting rapid growth of sulfate reducers. Corrosion, having been started by dissolved oxygen, can continue under the tubercle by means of sulfide attack.

Dissolved oxygen in a flood water usually produces a type of corrosion which is more general in nature with much less pitting than is found in the sulfide-type corrosion. The dissolved oxygen acts as a strong depolarizer in removing hydrogen from the cathode thereby enabling the corrosion process to continue.

The action of carbon dioxide in a corrosion process is that of formation of carbonic acid which is somewhat corrosive in the salt water environment. It does not create a problem nearly as severe as the one created by the presence of sulfide and/or oxygen.

Methods of Controlling Internal Corrosion

Control of corrosion caused by natural hydrogen sulfide will be considered first. In some cases hydrogen sulfide corrosion can be controlled by simple addition of an inhibitor to the water. Figure 5 shows reduction of corrosion coupon rates and reduction of the iron content treatment in a sulfide water.[1] Correlation of iron content values with corrosion rates were unusually good on this particular flood. Such treatment usually is less successful if there is appreciable build-up of organic slime or

and examining existing equipment. They are not, however, the best methods because they obviously depend upon hindsight. The four other methods of detecting or predicting corrosion rates are extremely valuable because they can be applied and their results evaluated during pilot flood operations.

Principal Causes of Internal Corrosion

Hydrogen sulfide, oxygen and carbon dioxide are the three principal corrosive agents in flood waters. Hydrogen sulfide corrosion is the worst of the three. However, a combination of hydrogen sulfide and oxygen probably creates the most corrosive environment found in normal water flood operations.

Hydrogen sulfide corrosion is greatly aggravated by formation and precipitation of iron sulfide on the pipe walls. The iron sulfide-iron galvanic cell thus created may result in extremely high localized corrosion with rapid failures by pitting. Under these conditions complete penetration of pipe walls within a few months time is common. Corrosion

rate in the pits may be several hundred mpy while the average rate over the entire surface of the pipe may be less than 10 mpy. Figure 1 is a picture of a new $3/16$-inch thick injection string which failed in 3.5 months because of sulfide pitting attack.[1]

Sulfide pitting-type corrosion usually can be detected by visual examination of exposed corrosion coupons. Average weight loss of a pitted coupon may be nominal so a report of the average mpy may not reveal the pitting. Visual examination and a report of the appearance of the coupons is very important with pitting-type corrosion. Figure 2 shows a metal-to-metal chrome plated pump plunger which was badly pitted in 35 days in water containing only 1.0 mg per liter of hydrogen sulfide.[1]

Corrosion probes have a much smaller exposed area than do coupons; therefore, the detection of pitting-type corrosion is even more difficult with the probes. Occasionally in a sulfide-type system a pit will start on the probe element thereby giving an extremely

Figure 6—Corrosion inhibitor comparison.

Figure 7—Valve spring retainers in service for 14 months in salt water containing 7 mg/liter of oxygen.

Figure 8—Triplex working barrel in service two years in fresh water containing 3 mg/liter of oxygen.

TABLE 1—Laboratory Comparison of Effectiveness of Five Bactericides for One Specific Flood Water*

Chemical	Concentration PPM**	Cost Mills/Bbl	BACTERIA PER CC	
			Aerobes	Sulfate Reducers
None...	—0—	—0—	1700	TNTC*** in 2 days
A	6.0	.77	210	None found
A	9.0	1.15	120	None found
A	12.0	1.54	27	None found
B	11.6	.77	550	1 in 4 days
B	17.5	1.15	410	None found
B	23.3	1.54	2	None found
C	8.25	.77	77	1 in 5 days
C	12.4	1.15	11	1 in 16 days
C	16.5	1.54	15	None found
D	15.	.77	900	TNTC in 3 days
D	22.5	1.15	850	TNTC in 3 days
D	30.	1.54	520	None found
E	15.	.77	450	TNTC in 2 days
E	22.5	1.15	110	TNTC in 3 days
E	30.	1.54	90	1 in 9 days

* Bacteria tests by Dr. C. C. Knoblock.
** Concentrations were selected on an equivalent cost basis.
*** TNTC = Too numerous to count.

mineral scale on the pipe walls. Foreign material clinging to the pipe walls permits deposition of iron sulfide which may create the serious galvanic cell action. Effectiveness of inhibitor treatment usually is influenced by the ability of the inhibitor to keep the internal surfaces clean. Inhibitor treatment probably will be unsuccessful if dissolved oxygen is present with the sulfide or if a second water containing dissolved iron is added to the system. The depolarizing effect of the oxygen makes inhibitor control extremely difficult and addition of ferrous iron causes precipitation of iron sulfide which sets up the galvanic cell action.

If an inhibitor will not provide satisfactory corrosion control, aeration should be used to remove the hydrogen sulfide. Forced-draft type aerators are preferred because they provide means of regulating the amount of aeration. The blower intake can be throttled to cut down

aeration or a by-pass line can be installed around the aerator and the amount of aeration can thus be controlled by varying the amount of by-pass water.

During aeration much of the hydrogen sulfide is driven off as free hydrogen sulfide gas. It is essential that retention time in a pond be provided to permit reaction of most of the remaining sulfide with the entrained oxygen. Water from a settling pond should be filtered and it probably should be treated with a corrosion inhibitor.

Figure 6 shows a comparison of two inhibitors in a system using aerated sulfide water. Inhibitor "B" is the most effective in this case but at least one other comparison on another flood showed inhibitor "A" to be the most effective compound.[1]

If iron sulfide deposition is a result of bacterial activity, the total amount of sulfide formed may be much less than that found in systems with high natural

hydrogen-sulfide content. Nevertheless, the iron sulfide thus formed may be enough to cause considerable corrosion in an unprotected system.

Bacteria counts should be made as a part of routine testing of flood waters. Appearance of significant quantities of hydrogen sulfide producing bacteria should serve as an immediate warning and treatment should be started anytime thereafter that significant iron sulfide deposition is found in the system.

Treatment for bacteria control can be effected with either a straight bactericide or with a combination corrosion inhibitor and bactericide. Chlorine is one of the cheapest of the bactericides; however, it has limited application because it tends to oxidize ferrous iron to the insoluble ferric iron and it has no corrosion inhibition qualities. There is some evidence that sulfate reducers may build up a tolerance for chlorine when the chemical is applied continuously.

The organic bactericides seem to have even less universal application than do the corrosion inhibitors. Laboratory determinations should be made for each specific application in order to select the most economical chemical. Such determinations also should provide some estimate of the starting concentration which should be used. Table 1 shows results of a laboratory comparison of 5 bactericides for one specific flood water.[1] Additional tests have shown different degrees of effectiveness in other flood waters.

Many combination bactericides and corrosion inhibitors fall in a price range of 1.5 to 3 mills per barrel of water treated. Chlorine sometimes will provide control at a cost of less than 1.0 mill per barrel of water.

Figure 9—Reduction of corrosion coupon rates with inhibitor treatment.

Figure 10—Cement-lined injection surface line in service eight years.

Corrosion which is accelerated by dissolved oxygen contamination can be retarded by one or more of three methods: (1) mechanical elimination of the oxygen contamination, (2) chemical removal of the oxygen by addition of reducing agent, and (3) corrosion inhibitor treatment. The first method usually is the best and cheapest if it applies to the situation.

Open siphon lines from gunbarrels are perhaps one of the most common sources of oxygen contamination. If the gunbarrel has appreciable gas in the vapor space, the open end of the siphon line should be tied-in to the top of the gunbarrel. Use of gas instead of air as a siphon breaker will solve the problem. Another common source of oxygen contamination is the transfer of water to a tank without extending the discharge line to a point below the minimum water level in the tank.

Oxygen contamination which occurs in tanks can be prevented by installation of a gas seal or it can be retarded by applying an oil seal to the water surface. Flumes or gas bleed-off valves may be used to prevent rolling in tanks, thereby reducing oxygen contamination.

Excessive drawdown of the fluid column in a water supply well can cause heavy oxygen contamination and serious corrosion throughout an injection system.

The foregoing types of oxygen contamination usually are easy to correct. The correction is relatively inexpensive because it involves a one-time mechanical change.

When surface waters are used, the problem is not one of preventing contact of the water with air but one of removing or combating the effect of existing oxygen. Chemical removal of oxygen may be justified, especially if the water is a brine and if the oxygen content is high. Chemical cost for elimination of oxygen from a water by treatment with sulfur dioxide gas will be about 1 mill per barrel for each 2 or 3 mg per liter of oxygen.[3] Sodium sulfite also can be used for oxygen removal.

Figure 7 shows severe oxygen corrosion of two valve-spring retainers from a triplex pump. Pump was in service 14 months in a brine containing 7 mg per liter of dissolved oxygen with approximately 60,000 mg per liter of dissolved solids.[1]

Some fresh waters with high dissolved oxygen content can be handled satisfactorily with corrosion inhibitor treatment. Successful inhibitor treatment becomes more difficult with increased mineral content.

Figure 8 shows attack by oxygen corrosion on a triplex working barrel which was badly pitted after two years of service. Fresh water which contained 3 mg per liter of oxygen was used.[1]

When corrosion is encountered in a brine containing carbon dioxide but no oxygen or hydrogen sulfide, the corrosion rate usually can be reduced to a satisfactory value by simple inhibitor treatment.

Figure 9 shows results of inhibitor treatment of a brine containing about 100 mg per liter of carbon dioxide and 125,000 mg per liter of dissolved solids.[1] The uninhibited corrosion rate of 10.4 mpy was reduced to less than 0.5 mpy. This excellent reduction was obtained with only 4 ppm of inhibitor at a low cost of 0.4 mill per barrel of water. This unusual success should not be considered as typical for water floods. Normal inhibitor costs are 1.0 mill per barrel or more.

Two additional methods of combating each of the foregoing types of internal corrosion are use of corrosion resistant materials and cathodic protection. Aluminum bronze impellers enclosed in cast iron cases in centrifugal pumps usually give good service. The cast iron is anodic to the bronze but it has a much larger surface area than that of the impeller so the combination often is satisfactory. Bronze meter parts, Monel sheathing of electrical lines to submersible pumps, cement lined pipe and fittings, plastic coatings, plastic equipment and porcelain pump plungers are common examples of
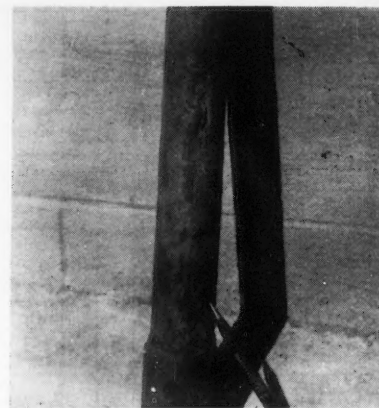
the use of corrosion resistant materials in water floods.

Cathodic protection can be used to retard internal corrosion in steel vessels such as filter shells, heater-treaters, water knockouts, water reserve tanks, the internal surfaces of stock tank bottoms. Rectifiers or sacrifical anodes can be used depending upon the economics of the particular application. Current densities of about 5 milliamperes per square foot should be used.

External Corrosion Problems

Buried Surface Lines

Detection of corrosion attack on existing buried water injection or oil gathering lines may be accomplished by visual examination at various places along the line and also by the use of corrosion survey instruments. If lines are to be laid in an undeveloped area, prediction of the corrosion rates must be based entirely on the instrument survey.

Pipe-to-soil potentials, surface potentials and soil resistivities are the most useful instrument determinations for detection or prediction of corrosion on an existing line.

If hot-spot cathodic protection is to be applied to existing, uncoated lines, the leak history should be examined for determination of locations of the obvious hot-spots. Surface-potential profiles and soil resistivity readings should be obtained to determine the location of additional hot-spots.

Magnesium anode installations usually are the most practical means of applying hot-spot cathodic protection to existing water flood lines. Rectifiers can be used economically in the plant areas. Magnesium anode installations on the injection lines of a water flood in 1956 reduced the leak incidence from more than 20 leaks per day to less than 10 leaks per month. Figure 10 shows a piece of 2-inch cement-lined pipe which failed as a result of external corrosion.[1]

Soil resistivity measurements should be made along the proposed right-of-way for new lines. These data should be used to determine, before the line is laid, the need for coating and/or cathodic protection.

When applying coatings to pipe for water flood use, consideration should be given to the relatively short life of the system. Large oil products lines may have an expected life of over 50 years whereas the average life for a water

flood may be close to 10 years. Coating requirements for water flood piping obviously are much less than those for the large pipe lines. Cathodic protection should always be used as a supplement when external coatings are applied.

Well Casing or Tubing

Corrosion of the external surface of the outside string of pipe in either an injection or a producing well can be retarded by applying cathodic protection. Either magnesium anodes or rectifiers can be used. Cost may be in the range of $15 to $35 per well per year.[4]

Cathodic protection is of no value in the annulus of a well. If corrosion in the annulus becomes a problem, inhibitor treatment or some other form of chemical treatment should be used.

Figure 11 shows external corrosion attack on a piece of 2-inch tubing. Considerable fluctuation of the fluid level in the annulus caused alternate exposure of a section of the pipe to air and water. Corrosion was controlled by introducing a column of inhibited oil into the annular space.

Conclusions

The pilot flood period should be used to establish whether an open or closed type of system should be used and to determine the most effective and economical type of water treatment.

All available methods of detecting and predicting corrosion rates should be used extensively during the pilot flood period.

The combination of hydrogen sulfide and oxygen contamination probably creates the most corrosive environment in water flooding operations. Prevention of the resultant iron sulfide precipitation or removal of the iron sulfide if it does precipitate will greatly aid in corrosion control.

Sulfate reducing bacteria can be serious contributors to corrosion and their control is advisable.

Mechanical improvements including use of corrosion resistant materials and cathodic protection may be cheaper and more effective than chemical treatment in some cases in reducing corrosion rates. However, treatment with corrosion inhibitors and bactericides are wise investments for many operators.

Where needed, conventional pipe line methods of coating and cathodic protection of lines should be used to control external corrosion. The expected life of the project is an important factor in determining the amount of money which should be spent for this type of corrosion control.

External corrosion of casing in either input or oil wells can be reduced by modern cathodic protection methods.

Use of corrosion resistant linings and/or corrosion inhibitors are recommended to help control internal corrosion of casing or tubing.

Acknowledgment

The author wishes to express his appreciation to R. C. Earlougher for
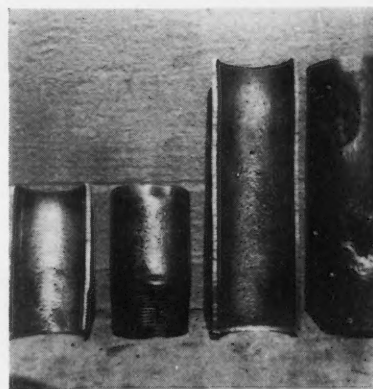
Figure 11—Injection well tubing from depth of fluctuating fluid level in annulus.

permission to publish this paper and for making available the data used.

References

1. Ray W. Amstutz. Operating Problems in Water-Flood Water Treatment, API paper No. 851-30-L.
2. A. H. Von Wolzogen Kuhr and L. S. Van Der Vlugt. Aerobic and Anaerobic Corrosion of Iron Water Mains. Translation by W. G. Bradley, U. G. Whitehouse, Dept. of Oceanography, A. & M. College of Texas, and Sgt. Pieter Groot, 1951.
3. J. D. Sudbury, C. F. Knutsan, Martin Felsenthal and J. D. Lung. Successful Conditioning of Pacific Ocean Water for Waterflood Injection, AIME paper No. 527-G.
4. Jack P. Barrett, Stanolind Oil & Gas Company. Verbal assistance.

Mounting External Casing Failures Worry T-1H

ELECTROLYSIS COMMITTEE of Southern California members who attended a meeting of the committee January 9 are shown. This committee recently affiliated with NACE's T-7 organization. Organized in 1925, regular meetings were held, except during World War II. Irwin C. Dietze, City of Los Angeles has been chairman since its reorganization in January 1947. Meetings are held bimonthly in the Water and Power Building, Los Angeles. It has 50 members and the job of secretary is rotated annually.

84 Activities Initiated by Technical Committees in '57

During the 12 months ending February 1, eighty-four new activities of NACE's technical committees were initiated. Committee membership now exceeds 1300 and the tendency of groups to meet more often than once yearly has accelerated. Numerous committee meetings were held at regional and sectional levels and there is every indication that meetings at these levels will be more frequent in the future.

During calendar 1957 twenty-five technical committee reports were published on information ranging from leakage conductance on buried pipe lines to effect of hot hydrogen sulfide on metals. Nearly a quarter of a million copies of technical committee reports were put into circulation.

In the report of the Technical Practices Committee to the NACE president, a summary of the work of the various technical committees was presented. These reports indicate that most of the subdivisions are actively at work on useful projects and that results of their work soon will be available for publication. In some instances, the subdivisions indicate an intention to confine their activities to discussion sessions, feeling that these are productive of results sufficient to more than justify the committees' existence. In at least one case a committee believes its forum is the only convenient place where users and suppliers may meet and discuss their joint problems.

Soft Pedal Paper Work

In most committees an effort is made to reduce the time devoted to administrative matters at meetings to the barest minimum so that more opportunity for profitable discussion is provided. This tendency has produced widespread, if not readily assessable, benefits to participants. It is noteworthy that at discussion sessions, non-member participants frequently equal and sometimes exceed in numbers the committee members present.

Some of the more recently organized task groups are engaged in activities designed to outline problems under consideration. After this preliminary has been accomplished, they will select an objective and work toward a report bearing on the problems specified.

New Groups Formed

Two new group committees were organized during the year. There are T-8, Refining Industry Corrosion and T-9, Marine Biological Deterioration. T-8 was organized at the 1957 annual conference and T-9 during a meeting with the Sea Horse Institute in June, 1957.

Cathodic Protection Proving Helpful in Limiting Damage

External casing failures were discussed by Unit Committee T-1H, Oil String Casing Corrosion, at its meeting on October 2, 1957, in Oklahoma City, Oklahoma.

A member said while failures were not widespread in the West Texas-New Mexico Area, they appear to be increasing. Only fields with known external failures were discussed.

Severest external corrosion reported was along the Howard-Borden County Line. Failures have occurred opposite the San Andres formation at a depth of 4700 feet. Cathodic protection is being applied from rectifier installations by five operators. Current requirements have been determined by both surface and subsurface methods and average 5 amperes per well. Three operators reported 5 failures in the Sprayberry Trend opposite the San Andres formation.

Over 200 Wells Protected

One operator is protecting 220 wells in the Midland Farms Field with magnesium anodes. Subsurface potential profiles indicate protection to a depth of 4000 feet.

One operator reported 2 casing failures at 380 feet in the Pembrook Field.

Danger of external corrosion in wells with casing set through San Andres formation was reported. The full extent or severity may not be evident at this time, because a large percentage of these wells are less than 10 years old.

Another member discussed the economics of protecting wells in the East Texas Field from external corrosion. Based on performance curves on wells in the East Texas Field, cathodic protection must extend the life of the casing 50 years to be economical. Initial cathodic protection installation costs from $250 to $350 per well with a power cost ranging from a few cents to $3.00 per month. Two amperes of current usually is adequate to protect the wells. Difficulty has been experienced with breaks in the ground connection attached to the braden head. Good agreement has been found between surface and subsurface methods of determining current requirements in the East Texas Field.

Survey Under Way

A member reported a survey of external casing corrosion is under way on the West Coast. The survey covers 21 percent of the wells in California. Data available indicate the average casing repair job costs $3200 and the average cost for cathodic protection is $1000 per well.

It is anticipated that external failures will occur in 200 wells per year. He discussed the wide discrepancies be-

| Backensto | Fenner | Stewart | Sudrabin | Vandelinder | Werner |

84 Activities—

(Continued From Page 71)

Numerous task groups have been formed throughout the committee structure. Some task groups have terminated their activities. The gain in task groups was 82.

The growth of T-7 Corrosion Coordinating Committee continues at a rapid rate. So far 15 local corrosion mitigation groups have affiliated, and there are indications that other groups may soon join. The committee is assisting in organizing groups in localities where no cooperative local organization presently exists.

Cooperation With Others

Cooperation with other technical organizations continues at about the same rate as in previous years. This involves liaison of one kind or another between NACE technical units and other groups to the extent of mutual exchange of reports in some instances and in others by verbal reports.

Cooperation continues with units in ASTM. Steel Structures Painting Council, Corrosion Committee of the Federation of Paint and Varnish Production Clubs, Construction Specifications Institute, National Association of Fan Manufacturers, API Division of Refining, Subcommittee on Corrosion, API Panel on Cooling Water, ASTM Committee D-19 on Industrial Water; A-10, Sub IV on Methods of Corrosion Testing, Society of the Plastics Industry, API Tanker Corrosion Committee, Chlorine Institute and American Welding Society.

Mounting External—

(Continued From Page 71)

tween current requirements in the Mid-Continent and West Coast. He suggested the possibility of comparing current densities in the different areas. Several members agreed to prepare data and submit it at the San Francisco meeting.

Officers Are Named By Four Groups for Current Year's Work

Two reappointments and two changes in officers of group committees have been made. Reappointed were: W. H. Stewart, chairman T-2; L. S. Vandelinder, chairman T-6; appointed, E. B. Backensto, chairman T-8 and elected, Daniel R. Werner, vice-chairman T-4. L. P. Sudrabin continues as vice-chairman of T-2 and O. H. Fenner as vice-chairman of T-6.

W. H. Stewart, Sun Pipe Line Company, Beaumont, Texas has been reappointed chairman of Technical Group Committee T-2 on Pipe Line Corrosion to continue work on the T-2 Minimum Requirements for Protection of Buried Pipe Lines. The committee expects to complete this report this year.

Werner Is Elected

Daniel R. Werner, American Telephone and Telegraph Company, Kansas City has been appointed chairman of Group Committee T-4 succeeding I. C. Dietze, chairman for the last two years.

An election for vice-chairman of T-4 will be held soon by letter ballot.

L. S. Van Delinder, Union Carbide Chemicals Company, South Charleston, West Virginia, has been reappointed chairman of Technical Group Committee T-6 on Protective Coatings. Mr. Van Delinder was appointed chairman last year succeeding L. L. Whiteneck.

O. H. Fenner, Monsanto Chemical Company, St. Louis, Missouri, continues as vice-chairman of T-6.

Backensto Heads T-8

E. B. Backensto, Socony Mobil Oil Company, Paulsboro, New Jersey has been appointed chairman of Technical Group Committee T-8 on Refining Industry Corrosion. He succeeds M. E. Holmberg who has been temporary chairman since the committee was organized in January, 1957. Mr. Backensto, a member of NACE since 1955, has been very active in NACE affairs.

A vice-chairman for T-8 will be elected by letter ballot soon.

NACE NEWS

SPECTATORS LOOK OVER the exhibits at the display by Niagara Frontier Section at the Buffalo Science Fair, February 18-20. A high order of interest in corrosion was shown by visitors, according to E. H. Caldwell. Many were surprised to learn how extensively corrosion control is a full time occupation for engineers in industry.

Chairmen Are Named For Teche Section's June Short Course

Six chairmen to manage activities at the coming June 4-6 Corrosion Short Course at Lafayette, La. were named at the February 27 meeting of Teche Section. Named by Section Chairman Suchanek were:

John D. Stone, Sunray Mid-Continent Oil Co., director and chairman of planning and program committee.

J. F. Shofner, chairman registration committee.

Phil C. Brock, Dowell, Inc., chairman housing and meals committee.

Lee R. DeRouen, Unim Oil & Gas Corp. of La., Lake Charles, La. chairman of speakers' committee.

John H. Selleck, Nocor Chemical Co., Lafayette, La. chairman of publicity committee.

Albert A. Prats, chairman of entertainment committee.

The course, to be held in cooperation with Southwestern Louisiana Institute, is the second to be sponsored by the section.

Sixteen members and 22 guests attended the February meeting to hear Wayne A. Johnson, Corrosion Rectifying Co. speak on "Use of Magnesium Anodes in Cathodic Protection."

D. R. Fincher, Tidewater Oil Co., Houston spoke to the March 27 meeting on "Recent Development in High-Pressure Condensate Well Corrosion Control".

W. H. Stewart, Sun Pipe Line Co., Beaumont will address the opening meeting of the Teche Section corrosion Control Short Course at be held at Lafayette, La. June 4-6.

TWO EXHIBITIONS BEING ORGANIZED

Two exhibits are being arranged now by NACE. R. W. Huff, exhibits manager at Central Office said that floor plans and contracts have been mailed to prospective exhibitors in the South Central Region exhibition at Hotel Roosevelt, New Orleans October 21-23. The 15th Annual Exhibition will be held concurrently with the conference at Sherman Hotel, Chicago March 17-19. Brochures and contracts for the Chicago exhibition will be mailed in May.

Firms interested in either or both of these exhibitions may get all the necessary information by writing to Mr. Huff at NACE Central Office.

Germanium Is Topic at Boston Joint Meeting

Chemical behavior of germanium surfaces in oxidizing media as influenced by surface treatment, crystallographic orientation and concentration of mobile carriers was discussed at a joint meeting of NACE Boston Section and the Boston Electrochemical Society local organization. The March 5 dinner meeting was attended by 37 of whom 19 were NACE members and some members of both organizations.

Harry C. Gatos, Group Leader of Lincoln Laboratory in Solid State Chemistry and Metallurgy, was the technical speaker. Principal media covered in his discussion were water containing dissolved oxygen and solutions of HNO_3 with varying amounts of HNO_2 and HF.

Industrial Uses of Aluminum Alloys Is Topic at Chicago

"Aluminum Alloys in New Chemical Process Industry Applications," and a film showing welding of aluminum were presented at the Chicago Section March 11 meeting. R. W. Flournoy, Reynolds Metals Co., Louisville, Ky. was the speaker.

Mr. Flournoy described advantages in using aluminum in low temperature service, to —420 F. Use of aluminum in large water tanks of 200,000 to 300,000 gallons capacity was explained. Other uses described were extruded duplex tubing; welding of tubing too large to be extruded; and use of welded pipe in the legs of aluminum offshore drilling derricks in Lake Maracaibo. Derricks are 100 to 120 feet high and weigh about 40 tons each.

Aluminum welded pipe has been proposed for use in water ducts and penstocks up to seven feet in diameter. Tapered plate can be rolled in lengths to 60 feet by 10 feet wide and its use provides about 15 percent savings in metal over stepped plate fabrication. Advantages of aluminum jacketing for covering pipe insulation and its use in catwalks, railings and ladders was described.

New combinations of aluminum and plastics were given. Plastic piping fittings can be used in aluminum piping systems and proposed combination uses of aluminum and plastic appears promising, according to Mr. Flournoy. Aluminum pipe with PVC internal lining is in the developmental stage and promises to give excellent corrosion resistance, moderate strength and low cost.

One proposed low temperature use of aluminum was in construction of tanks for tank ship transportation of liquefied methane and natural gas. Tanks would be 60 by 35 by 45 feet and would be insulated for cooling to —259 F.

Uses of aluminum in handling anhydrous ammonia, hydrogen peroxide were given. Distilled, demineralized and condensate water and resistance to corrosive action of chemicals for treating boiler feedwaters were discussed.

Fifty-four members and guests atteded the meeting. Preceding the technical session, V. M. Kalhauge, Standard Oil Co., Indiana, conducted a brief business session. Ivan Acosta, Crane Co., introduced the speaker.

Pratt & Whitney Plant at East Hartford Is Toured

Southern New England Section members planned a tour of the Pratt & Whitney Aircraft plant, East Hartford, Conn. in addition to their technical program for their April 16 meeting. The afternoon tour was scheduled to precede the dinner meeting in the Bond Hotel, Hartford.

Ralph W. Moeller, Pratt & Whitney Aircraft Div., United Aircraft Corp. was the speaker on "Trends in Surface Protection of Metals."

Clayton Rand to Be New Orleans Speaker

Clayton Rand, editor of the Dixie Guide, Gulfport, Miss. author and nationally-known after-dinner speaker will talk at the 1958 South Central Region Conference at New Orleans October 20-24. Mr. Rand, with a long background in newspaper work and public speaking is rated by many as one of the leading afterdinner speakers in the nation.

Rand

A graduate of Harvard and Mississippi State College, he has practiced law in Mississippi, published country weekly newspapers since 1919, won national

EXHIBITORS' CONTRACTS MAILED

Exhibitors' contracts for the October 21-23 exhibit to be held during the South Central Region Conference at Roosevelt Hotel, New Orleans have been mailed. The contracts, floor plans and explanatory letters were sent to 439 companies which are prospective exhibitors. Additional copies of the literature are available or request from Central Office, NACE by companies or individuals interested in the show. The exhibit is expected to attract a representative group of engineers interested in corrosion control, especially in the petroleum, natural gas and petrochemical fields.

editorial awards, authored several books and he is author of a daily syndicated newspaper feature also. Mr. Rand's speaking engagements have been scheduled into 1959.

Fred O'Rourke, Harvey, La. has replaced Fred McDougall as chairman of the conference. Mr. McDougall was transferred from New Orleans.

Cincinnati Meeting Symposia Scheduled

Seven symposia covering the process industries, nuclear energy applications, utilities and coatings and including two on metals are scheduled for the October 15-17 North Central Region meeting at Cincinnati. Two educational lectures also will be given.

The symposia are planned as follows:

October 15
Corrosion Problems in the Process Industries
Stress Corrosion Cracking in Austenitic Stainless Steels
Educational Lecture: Corrosion in Rocket Technology
October 16
Corrosion Problems in the Nuclear Field
Protective Coatings, Inorganic
Corrosion Problems in Utilities Industries
Eductional Lecture: Useful Applications of Corrosion
October 17
Protective Coatings: Organic
New Metals and Alloys

Carolinas Section, ACS Hold Midwinter Meeting

Carolinas Section held a joint meeting with the local chapter of American Chemical Society, as a feature of its midwinter meeting Charlotte, N. C., Feb. 12. Norman Hackerman, director of corrosion research laboratory at the University of Texas gave a technical talk on "The Mechanics of Corrosion Inhibition." Fifteen members and 60 guests were present.

NEW WESTERN REGION chairman for 1958, E. F. Bladholm, Southern California Edison Co., Los Angeles, accepts the gavel from L. Magoffin, California Water and Telephone Co., San Marino, the out-going chairman. New region officers were installed at the January 29 meeting of the Los Angeles Section. L. L. Whiteneck, Plicoflex, Inc., Los Angeles, president of NACE explained the benefits of corporate membership to the group. Three technical talks were delivered. Barrie Best, Parker Brothers, Inc., Los Angeles, spoke on "Coating Testing Instruments." G. H. Rohrback, Magna Products, Inc., Santa Fe Springs, Calif. spoke on "Corrosion Measuring Instruments Based on the Electrical Resistance Method."

Shreveport Barbecue Scheduled for June 6

Shreveport Section will hold its annual barbecue, June 6. Details have not been announced.

At the April 1 meeting, Lewis J. Adams, Republic Steel Corp., Dallas, spoke on "Use of Plastic Pipe in the Oil and Gas Industry." A movie, "Pipe Lines of the Future," was shown also. The meeting was held at Caddo Hotel Coffee shop.

Sixty persons among the 135 registered for the Shreveport Section corrosion control Short course held February 13-14 at Centenary College attended for the first time. The course covered all phases of underground corrosion and its mitigation, oriented for field personnel and management. There were ten lecturers.

Section members considered this course highly successful because of the large attendance. M. J. Olive, Arkansas Fuel Oil Corp. was general chairman.

All meetings of Shreveport Section now are held at the Caddo Hotel on the first Tuesday monthly.

The use of coated magnesium anodes on the water side of coolers and condensers in gasoline plants was discussed by M. J. Olive, Arkansas Fuel Oil Corp., Shreveport at the March 4 meeting of Shreveport Section. Mr. Olive's talk was titled "Cathodic Protection in Gasoline Plant Process Equipment."

A change was made in section officers. R. P. Naremore, Arkansas Fuel Oil Corp., formerly treasurer is now secretary. Grady Howell, Tube-Kote, Inc., formerly secretary, is now treasurer.

•

An average of four to six short courses on corrosion control are held in the United States yearly with cooperation of NACE.

Wachter to Represent NACE at Frankfurt

Aaron Wachter, head of the Corrosion Department of Shell Development Co., Emeryville, Cal. and formerly president of NACE has been named official representative of the association to the Congress of the European Federation of Corrosion, June 1-7 at Frankfurt on Main, Germany. Dr. Wachter, who has long been active in NACE as a member of the board of directors, chairman of local sections, and of technical programs, will be in Europe during the time of the Frankfurt meeting.

Wachter

Fundamentals Is Topic At San Diego Section

A discussion of fundamentals of corrosion aimed at a predominantly non-technical audience was enthusiastically received at the March 12 meeting of the San Diego Section.

D. P. Armbruster explained the corrosion process in layman's terms first and then explained it in technical engineering terms. Starting with the atomic theory, he terminated his talk by explaining the generally accepted methods of corrosion control today.

A suggestion from the floor that the paper be submitted for printing in "Corrosion" as a basic corrosion course for non-technical members of NACE was unanimously approved. In pointing up the need for such a course, one member stated that only 10 percent of the San Diego Section are technical men and that 90 percent have a need for a basic corrosion course.

The meeting was held at Lawton's restaurant, La Mesa, Cal.

Panel at New York Talks About Zinc-Rich Paint

A discussion panel on zinc-rich paints was scheduled for the April 10 meeting of the Metropolitan New York Section. Selected on the panel were: George W. Ashman, The New Jersey Zinc Co.; J. Glen Lacy, The Amercoat Co.; Spencer W. Shepard, The Chemical Construction Corp. and Ernest H. Thulman, Ebasco Services, Inc. A motion picture on zinc-rich paints was scheduled to precede the discussion. Chi-Am Chateau, Westfield, N. J. is the meeting place.

Central Arizona Section Installs New Officers

Installation of new officers for 1958 was the principal event at the Central Arizona Section's February 27 meeting. Harold B. Newsom, Rust Proofing, Inc., was elected chairman; William B. Lewellen, Deer-O-Paints and Chemicals Ltd., vice-chairman; and Lee Homrighausen, Arizona Public Service Co., secretary. All live in Phoenix. The meeting was held at Rust-Proofing Inc., Phoenix, Ariz.

Southwestern Ohio Section To Elect New Officers

Election of new officers for the Southwestern Ohio Section was scheduled for early April. Officers to appear on the letter ballot are W. E. Hare, Hare Equipment, chairman; R. L. Wood, Cincinnati Gas & Electric Co., vice-chairman; Clifford H. Jones, secretary and A. D. Caster, treasurer. Nominees were approved for the ballot at the March 25 meeting in Cincinnati.

Nominated for the board of directors were: G. H. Cantwell, Indiana Bell Telephone Co., Indianapolis, Ind.; R. F. Andres and R. B. Stevenson, Dayton Power & Light Co.; Josephine Williams and L. M. Lederer, Inner-Tank Lining Corp., Cincinnati, Ohio.

A meeting was scheduled for March to plan for the October North Central Region Meeting. Roy O. McDuffie, University of Cincinnati, is co-chairman for the region meeting.

Technical speaker for the March meeting was Ralph E. Madison, Truscon Laboratories, Division of Devoe-Raynolds Company, Inc. He presented an illustrated talk outlining laboratory tests on epoxy resin coatings for metals and described a newly developed chemical resistant epoxy top surface materials for concrete floors.

•

Maps of the miles of metal pipe, power and communication cables underground in large metropolitan areas are being mapped by committees affiliated with NACE's T-7 committee.

Houston Section Picnic, Golf Tournament Scheduled

It will be "plenty of food, swimming and dancing" at the Houston Section "NACE Play Day Picnic," May 13 at the Texaco Country Club, according to section program officials. A "Blind Bogey" golf tournament (open to duffers as well as skilled gulfers) will be held.

At the April 8 meeting, 110 section members and guests heard Raymond B. Seymour, president of Loven Chemical of California speak on plastics. Mr. Seymour pointed out the tremendous growth of plastics since his association with the industry.

He pointed out several cases where the use of plastics had provided good solutions to corrosion problems. In one unusual case, a plastic lining in pipe prevented freezing water from breaking the pipe. He recommended general practices which should be followed in selecting the kind of plastic to be used to prevent corrosion, and the manner in which it should be applied. The meeting was held at John's restaurant and was preceded by a dinner and fellowship hour.

South Central Region Meets In Houston, October 1961

Houston's Shamrock Hotel has been selected as the site for the October 24-27, 1961 meeting of South Central Region.

South Central Region Sets Meeting Dates Through '62

Meeting dates through 1962 have been scheduled for conferences of South Central Region as follows:
1958—New Orleans, October 20-24.
1959—Denver, Col., October 12-14.
1960—Tulsa, Olka., no dates set.
1961—Houston, Texas, October 24-27.
1962—San Antonio, Texas, October 16-19.

Western Region's Fall Meeting at Los Angeles

The annual fall meeting of Western Region will be held November 17-19 at Los Angeles' Statler Hotel.

During 1957 NACE distributed more than 226,000 copies of its technical committee reports.

200-hour torture test proves
REG. U.S. PAT. OFF
SCOTCHRAP superiority!
BRAND
PIPE PROTECTION TAPE

Each of these 5 standard pipe lengths was covered with a different commercial pipe "protective" coating—both tapes and mill-coatings. All five pipes were then put in the barrel shown with an abrasive-chip tumbling medium and continuously tumbled for 200 hours. This unretouched photo shows the results: only the pipe coating on the extreme right survived *intact*—the pipe wrapped in "SCOTCHRAP" Brand Pipe Protection Tape. This photo shows clearly and dramatically why "SCOTCHRAP" gives such superior performance in resisting abrasion from backfilling and underground soil stresses. Add to this the superior resistance to electrolytic forces . . . the superior shear adhesion strength . . . and the new low prices, and you have the reasons why we believe "SCOTCHRAP" Pipe Protection Tape is your best total coating buy for entire distribution systems.

"SCOTCHRAP" is a registered trademark of 3M Co., St. Paul 6, Minn.

"SCOTCHRAP" Pipe Protection Products

LOOK what you can do with "SCOTCHRAP"
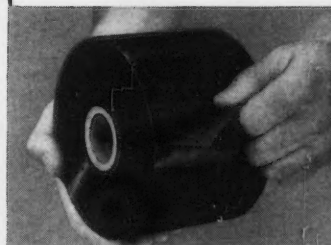
MAKE QUICK, easy applications to any size pipes. "SCOTCHRAP" is specially formulated polyvinylchloride in handy tape form. It is tough, but conformable; sticks at a touch . . . no heat . . . no mess!
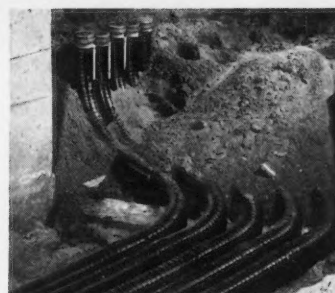
ACTUAL field use shows why abrasion-resistance of "SCOTCHRAP" is important: backfill is coarse, rough—could easily puncture or tear less tough coatings.
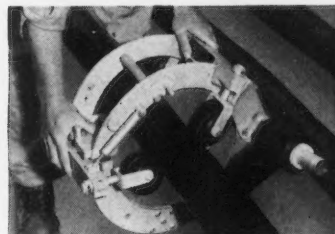
SAVE TIME on total system coverage. With wide-width "SCOTCHRAP" and "Betzel" Tapester, one man covers 200 feet of 4″ pipe in less than 30 minutes.
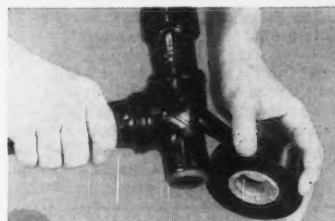
INSULATE joints, tees, elbows in the field. Supercomfortable "SCOTCHRAP" does it quickly. For complete information on "SCOTCHRAP", or to arrange demonstration, write: 3M Co., 900 Bush Ave., St. Paul 6, Minn., Dept. BQ-58.

MINNESOTA MINING AND MANUFACTURING COMPANY
. . . WHERE RESEARCH IS THE KEY TO TOMORROW

3M COMPANY

PERMIAN BASIN SECTION members confer with Rupert Poetker, Sunray Mid-Continent Oil Co. (third from left) at the March 11 meeting of the section. Others are, left to right, R. C. Booth, Plastic Applicators, Inc.; Kirk Harding, Gulf Oil Corp. and Roscoe Jarman, Nocor Chemical, Inc.

SOME INTERESTING INFORMATION holds the attention of the speaker and four other persons at the Permian Basin Section April 8 meeting. From left to right they are: seated, M. J. Olive, Arkansas Fuel Oil Corp., who spoke to the group on "Cathodic Protection—Oilwell Casing and Surface Equipment"; and Paul Cameron, Pure Oil Co.; standing, Tony Howard, Pure Oil Co.; Bob Naremore, Arkansas Fuel Oil Co. and Mike Deodati, Tretolite Co. Forty-five persons attended the meeting. At the May 14 meeting, the section will hear John V. Gannon, the Texas Co., speak on the "Company Corrosion School." The meeting will be held in Midland.

North Texas Section Learns Sweet Oil Does Corrode

Rado Loncaric, Atlantic Refining Co., Dallas left no doubt that severe corrosion can result from sweet crude in his talk before North Texas Section March 3. The meeting was held at Fort Worth with 22 members and four guests present.

Of the four guests one was a Houston section member, one has applied for membership and the other two received membership application blanks.

Squeeze Inhibition Reduces Corrosion, Poetker Asserts

The inhibitor squeeze method has reduced corrosion control costs in several installations where it was started several months after the use of inhibitors by other methods had begun. Rupert Poetker, Sunray Mid-Continent Oil Co., Corpus Christi gave this information during his talk "Does the Squeeze Inhibitor Method Work?" before 63 members and guests of Permian Basin Section March 11.

Mr. Poetker also said baked-on plastic linings are being used successfully in high fluid wells in the same fields.

Etex Section Hears Brock Talk On Squeeze Inhibition

Inhibitor squeeze in gas condensate wells was the subject presented to the East Texas Section at its March 25 meeting. Phil Brock, Dowell, Inc., the speaker said the inhibitor squeeze method is most economical in very high pressure wells or wells that must be produced continuously or shut in only infrequently for treatment.

An advantage of the method is that inhibitor is applied where it is most needed, at the bottom of the hole, he said. A single treatment may be effective for six months or longer, depending on individual well conditions. The meeting was held at Hotel Longview, Longview, Tex.

Scheduled for the April meeting was a talk by Kenneth Tator of Kenneth Tator Associates, on the subject, "Corrosion Preventive Coating Information."

Technical Directory Is Due

A 1958 Directory of Technical Committees will be published this year. A decision on publication of a 1959 membership directory and year book will be made by the NACE board at a later date.

Central Oklahoma Section Learns About Conoco Research

Central Oklahoma Section changed its regular meeting date from the second Monday to the first Monday in May so the section could meet in Ponca City. John D. Sudbury spoke on basic research, and James E. Landers on field research and development. The talks principally concerned fundamental and applied research currently being carried on at Continental Oil Company's Central Research Division in Ponca City. Also planned for the meeting was a conducted tour of Continental's Gamma Ray Radiation Laboratory and Corrosion Research Laboratory. A dinner at the Mark Restaurant was to be followed immediately by the technical meeting.

Scheduled for April 14 at Oklahoma City was a "Soil Box Demonstration" by O. W. Everett. It is maintained that 45 minutes with the soil box demonstration is the equivalent of from three to four hours intensive class room instruction in the fundamentals of corrosion. The talk was aimed at showing supervisory men how the unit is used to teach fundamentals of corrosion control.

Following a decision of the March section meeting, the mailing list of members is being revised. A roster of section members with their addresses was mailed in April to all members. A return post card requesting address and other information was enclosed with the roster.

D E A T H S

Clair O. Evans, Phelps Dodge Copper Products Corp., New York, N. Y., died December, 1957. He had been a member of NACE since 1948, and at that time had been working as a corrosion engineer for 25 years, specializing in corrosion problems in condenser tubes, public utilities and marine service.

George A. Rossney, 65, sales representative of the protective coatings division of Pittsburgh Coke & Chemical Co., died suddenly of a heart attack, February 16, 1958. Mr. Rossney had handled sales of Insul-Mastic Karkote to the automotive industry in the Buffalo, N. Y. area for 10 years, both before and after Pittsburgh Coke & Chemical Co. acquired Insul-Mastic. He was associated formerly with Cleveland Paint Co., Bell Aircraft Corp. and the American Lubricant Co. He is survived by his widow, Hildegard; four sons, Warren G., Glenn A., Earle J. and George E. and a brother, Edward J. Rossney.

Roy R. Riordan, 50, salesman for Plastic Engineering and Sales Corp., died of a heart attack March 21st. He had been associated with Pesco for the past two years, travelling in Arkansas, Louisiana and Mississippi.

•

NACE cooperates with numerous other engineering and scientific organizations all over the world in the collection and dissemination of corrosion control information.

Alamo Section Meets At Texas University

Alamo Section scheduled its regular monthly meeting for April 15 on the University of Texas campus in Austin. Norman Hackerman, the University of Texas Chemistry Dept. was scheduled to speak on "Recent Experiments in Corrosion." A dinner preceding the business and technical session was planned to be held at a nearby restaurant.

"Oil and Gas Well Corrosion," a film concerned with corrosion inhibition was scheduled for presentation to the March 18 meeting of Alamo Section. S. A. Huckleberry, Dowell Inc, Houston, presented the film.

•

South Central Region's 1961 Conference will be held October 24-27 at Houston's Shamrock Hotel.

TECHNICAL REPORTS

on

CORROSION in UTILITIES

T-4B Cell Corrosion on Lead Cable Sheaths. Third Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-1 on Corrosion of Lead and Other Metallic Sheaths. Publication No. 56-9. Per Copy $.50.

T-4B-2 Cathodic Protection of Cable Sheaths. Fourth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Compiled by Task Group T-4B-2 on Cathodic Protection. Publication 56-13. Per Copy $1.00.

T-4B-3 Tests and Surveys for Lead Sheathed Cables in the Utilities Industry. Second Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths. Publication 54-6. Per Copy $.50.

T-4B-4 Pipe-Type Cable Corrosion Protection Practices in the Utilities Industry. First Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, Corrosion, Sept. 54 issue. Publication 54-3. Per Copy $1.00.

T-4B-6 Stray Current Electrolysis. Fifth Interim Report of Technical Unit Committee T-4B on Corrosion of Cable Sheaths, prepared by Task Group T-4B-6 on Stray Current Electrolysis. Publication No. 57-1. Per Copy $1.00.

T-4F-1 Progress Report of Task Group T-4F-1 on Water Meter Corrosion. Per Copy $.50.

TP-12 Report on Electrical Grounding Practices. Per Copy $.50.

TP-19 Corrosive Effects of Deicing Salts— A Progress Report by Technical Practices Committee 19. Corrosion, January, 1954, issue. NACE members $.50; Non-members $1 per copy.

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg.   Houston 2, Texas

NOMINATING COMMITTEE REPORT TO BE PUBLISHED

The report of the NACE nominating committee for national officers and directors representing active and corporate membership will be published in the June issue of CORROSION. This publication will serve as notice to the membership of the recommendations of this committee prior to initiation of the voting procedure.

More than a thousand NACE members and 246 technical advisers are members of NACE technical committees.

POSITIONS WANTED and AVAILABLE

- Active and Junior NACE members and Companies seeking employees may run without charge two consecutive advertisements annually under this heading, not over 35 words set in 8 point text type.
- Advertisements to other specifications will be charged for at $10 a column inch.

Positions Wanted

Englishman, 3 years' experience in marine, industrial and underground cathodic protection field, office supervising, sales and consultancy. Age 30. Married. Will accept Canada, USA or Europe. CORROSION, Box 58-7.

Five and one-half years' experience in cathodic protection and corrosion engineering work. Desire location in Southwest. Would consider foreign location. Reply to CORROSION, Box 58-6.

Positions Available

Operations Superintendent—Opening in medium sized natural gas utility in Midwest for an able graduate engineer or equivalent to supervise construction, maintenance, service on customer premises, appliance installation, metering, pressure regulation and planning system expansion. Liberal benefits. Salary commensurate with experience and ability. State personal and educational qualifications. CORROSION, Box 58 - 4.

Wanted! Corrosion engineer with paint experience to sell corrosion barrier coatings and industrial paints in Southern Louisiana and Gulf Coast territory from Houston to New Orleans. Address correspondence to Ainslie Perrault, President, Allied Paint Mfg. Company, P. O. Box 1088, Tulsa, Oklahoma.

Leading Manufacturer of complete line acid proof cements, acid brick, coatings, other specialties in corrosive field, requires aggressive commission representatives. Exclusive franchises, excellent commissions, established accounts, rare opportunity. Franchises open in all major industrial areas in U. S. Sales to steel, chemical, food processing industries. Write experience, lines handled, territory traveled to CORROSION, Box 58-5.

CORROSION COATINGS SALESMAN

We are interested in obtaining the services of a man preferably with sales and service experience in the anti-corrosion coating field to represent us in the greater New York area. Our line of outstanding Copon coatings offers an excellent opportunity for the right man. Address reply in confidence to Ray H. Sommer, giving full details including salary desired. Brooklyn Paint & Varnish Co., Inc. 50 Jay Street, Brooklyn 1, New York.

Hamner   Longino   Vander Henst   Rolak

ABOUT NACE STAFF

NORMAN E. HAMNER—Managing editor and advertising manager of CORROSION since October 1948, he previously was employed as editor and managing editor, and in the advertising departments of daily and weekly newspapers in Texas and Louisiana since 1928 except for service in the army. During World War II he was an infantry platoon leader in the Normandy invasion and presently is a member of the army reserve as a staff specialist attached to the troop information section of Fourth Army headquarters, San Antonio. He attended public schools in New Orleans, Tulane University and University of Houston. He is married and has lived in Houston since 1946 after his return from army service.

JAMES T. LONGINO—Technical editor of CORROSION since June, 1955. He formerly was a reporter on the news staff of the El Paso Herald-Post. He has a 1951 BA from Rice Institute and an MS in journalism three years later from Columbia University. During the Korean War he served two years with army intelligence. He is interested in short story writing, music, English literature and spectator sports.

G. A. ROLAK—Has been employed by NACE since October, 1955. He formerly was employed in clerical capacities by Houston firms, has an AA degree from Lon Morris Junior College and presently is attending University of Houston. He is a member of the Air Force reserve. His principal interests include fishing, education and fine arts.

J. F. VANDER HENST—Employed by NACE since January, 1955, he formerly was employed at the Dickinson Gun Plant, Houston for four years and from the time of his discharge from the army in 1947 to 1951, worked for a bank. He attended Rice Institute, majoring in chemical engineering. During World War II he spent two years in the army including one year with the engineering section of the 8th Army in Japan. He is married and has two children. His principal sport is bowling.

Realignment of NACE Staff Duties Announced April 1

A realignment and assignment of duties to members of the NACE Central Office staff has been made effective April 1. T. J. Hull, new executive secretary, in announcing the changes, said "These assignments are made in expectation that an efficient and satisfactory operation of Central Office staff will result. Our aim is to improve our services to our membership and make best use of the abilities of our staff."

While shifting of responsibilities and work has been extensive in most departments, the changes of immediate importance were:

Publications Director—Norman E. Hamner, since October, 1948 managing editor and advertising manager of CORROSION has been given the added duties of handling most of the association's publications. The principal publication activities of the association, CORROSION, abstract publications, yearbook, and other miscellaneous publications will be under his supervision.

Technical Editor—James T. Longino, who has been editor of material published in CORROSION's Technical Section since June, 1955 will continue to handle this work. The volume of work handled by Mr. Longino has increased to the

Drive to Add New Corporate Members Gains Momentum

A drive to add new corporate membership to the association has reached the point where the basic organization is complete and concentrated work is under way to secure added support for NACE. W. H. Stewart, Sun Pipe Line Co., reported to the NACE board at its March 15 meeting that most of the persons in the sections who will assist in the program have been named.

The increase in corporate memberships is an aim of the association so that NACE work can be expanded in fields where it has been unable to func-

Directories' Publication Schedule Is Revised

The following schedule for publication of directories is effective with this (May, 1958) issue of CORROSION:

Corporate Membership Directory	February, May, August, November
Region and Section Officers	March, June, September, December
Technical Committee Officers	January, April, July, October

In the intervening months changes in officers of regions and sections will be published. Changes in technical committee officers will not be published in intervening months.

tion because of limited finances. Income from corporate memberships represents a substantial portion of the NACE total revenue.

Numerous projects that have been held in abeyance during the years may be reconsidered if a substantial increase in revenue is obtained in the current drive. Solicitation of new memberships by mail is under way. Cooperation of all NACE members in promoting this drive has been asked by President Whiteneck and the board of directors.

Any person interested in helping NACE in the program may get full information by writing to T. J. Hull, executive secretary at Central Office NACE.

point he is fully occupied with technical editing.

Technical Committee Secretary—J. F. Vander Henst, who has been handling administrative work connected with technical committees along with other duties, will devote his full time to the committees. The increasing activities and growing number of committees makes this virtually a full time job for one person.

Administrative Assistant for Regions and Sections—G. A. Rolak, who started working for NACE in October, 1955 in the mail department, will handle correspondence pertaining to the regions and sections and other related work. He also will have charge of the ordering, production and delivery of reprint copies of NACE technical material.

•

North Central Region will hold its 1958 meeting October 15-17 at Cincinnati.

S

Inh
He

F
lec
pec
n

M
he
ser
as.
vor
sea
pro
sec
ore
ern
with

M
Tex
Res
whe
hibi
velo
nate
MS
bur

C
San
nua
Gro

AMC
meet
feren
Jack
and

T-6A
coat
Vollr
Pitts
Beav
ton
S. K
road
Nick

Ri
P. E.
Fran
South
Dani
grap
Gene
Skinr
York
& W
Fenn

San Francisco's Technical Program Is Praised

Inhibitor Group Elects, Hears Sour Crude Report

E. J. Simmons, Sun Oil Co., and C. . Nathan, The Texas Co. have been lected chairman and co-chairman repectively of Technical Committee T-1K n Inhibitors for Oil and Gas Wells.

Mr. Simmons is supervisor of the hemical test section of the Production Service Laboratory, Sun Oil Co., Dalas. The section includes special groups vorking on corrosion service and research, analytical testing and special problems including chemical aspects of econdary recovery. Mr. Simmons majored in chemistry and biology at Southrn Methodist University and has been with Sun since 1940.

Mr. Nathan, is research chemist at Texaco's Exploration and Production Research division at Bellaire, Texas where he is working on corrosion inhibition. He holds three patents for developments in this field. He is a graduate of Rice Institute, and received his MS and PhD at the University of Pittsburgh.

Sour Crude Report Given

Committee T-1K held a meeting in San Francisco at the NACE 14th Annual Conference. A report of Task Group T-1K-1, on Sour Crude Inhibitor

---

AMONG THE 80 TECHNICAL Committee meetings during the March 17-21 NACE Conference were: left, top to bottom: T-1 meeting, Jack L. Battle, Humble Oil & Ref. Co., Houston and H. M. Cooley, Bethlehem Steel Co., Tulsa;

◄——

T-6A C. G. Munger and J. I. Richardson, Amercoat Corp., Los Angeles; T-1F (at table) L. W. Vollmer, Gulf Research & Development Corp., Pittsburg; H. M. Cooley and T. M. Krebs Beaver Falls, Pa.; T-2D, Marshall Parker, Houston and L. F. Heverly, Lima, Ohio; left, T-3C, S. K. Seymour, Association of American Railroads; right, T-3G, T. P. May, The International Nickel Co., Inc., Kure Beach;

Right, top; T-2H, left, unidentified and right, P. E. Reynolds, Pacific Gas & Electric Co., San Francisco; T-2B, at microphone, J. J. Dorsey, Southern California Gas Co., Los Angeles; T-4B, Daniel R. Werner, American Telephone & Telegraph Co., Kansas City; T-5B, R. T. Foley, General Electric Co., Schenectady, N. Y.; E. N. Skinner, The International Nickel Co., New York; bottom, left, T-3F, R. U. Blaser, Babcock & Wilcox Co., Alliance, Ohio and right, Otto F. Fenner, Monsanto Chemical Co., St. Louis.

Nathan   Simmons

Evaluation was given by Roy D. Stanphill, Humble Oil & Refining Co. New chairman of this Task Group is John R. Bruce, Shell Oil Co. Status of work of Task Group T-1K-2 on Sweet Crude Inhibitor Evaluation was presented by E. J. Simmons.

Parent Committee T-1K is working on high-temperature testing of inhibitors. NGAA subcommittee E has presented this problem to Task Group T-1B-1 on High Pressure Well Completion and Corrosion Mitigation Procedure. This problem will be referred to committee T-1K for consideration. D. R. Fincher, Tidewater Oil Co. will coordinate this work under supervision of Jack Barrett, Pan American Petroleum Corp.

High Temperature Group

Tentative plans are to form a task group for high temperature work under direction of Mr. Barrett.

In other committee activities, plans are to submit recommended alternate screening tests for sour crude inhibitors, then work on evaluation tests for both sweet and sour crude, along with high temperature evaluation tests in sour, sweet and acid type corrosion. An estimated 36 persons attended the meeting.

Vigorous Discussion Held On Railroad Corrosion

Technical Committee T-3E on Railroads held a round table meeting during the NACE 14th Annual Conference. Chairman L. J. Nicholas, The Pullman Co. presided.

There was a vigorous discussion of railroad corrosion problems and their possible solution, with enthusiastic participation by the entire group. As a project, the committee will publish a newsletter. Thirteen members attended the meeting.

Good Planning Is Credited for Smoothly Functioning Sessions

The high caliber of the technical presentations at the 14th Annual Conference held in San Francisco was the most frequently mentioned feature of the meeting. Registrants attending were kept busy shuttling between meetings of technical committees and symposia with frequent stops at the exhibition.

Preliminary planning made conference events run smoothly. There were sufficient rooms of adequate size in the San Francisco civic auditorium for both committee meetings and symposia. The revised schedule of opening and closing hours and days was approved generally by exhibitors, who reported satisfactory attendance and good interest in the show.

Total registration reported by General Chairman D. R. Loper, Standard Oil Co. of California, San Francisco, was 1731, of which 1190 were paid and 541 exhibitors' registrations. Of the paid registrations 177 were by ladies. Mr. Loper also said the policy of distributing preprints from the NACE booth on the day following presentation of technical papers was not entirely satisfactory, but was considered to be the best arrangement perfected so far.

San Francisco Charms

San Francisco proved to be as fascinating as advance information indicated it would be. Registrants were able to visit many of the scenic, historical and gustatory attractions while participating in a full schedule of technical and enter-

---

MORE TECHNICAL MEETING scenes (at bottom of page) left to right, During presentation of "Corrosion Problems Associated With Uranium Refining," at Chemical Industry Symposium, R. E. Gackenbach, American Cyanamid Co., New York, seated at right; Refinery industry round table left to right, R. W. Manuel, Socony Mobil Oil Co., New York; M. E. Holmberg, Houston; E. B. Backensto, Socony Mobil Oil Co., Paulsboro, N. J.; Cecil Phillips, Jr., Humble Oil & Ref. Co., Baytown; right at Refining Industry Symposium, left to right, E. L. Hildebrand, Humble Oil & Ref. Co., Baytown, Texas; at microphone, R. W. Manuel; and C. M. Schillmoller, The International Nickel Co., Inc., Los Angeles.

Surface Preparation Specifications Is New Project for Protective Coatings Committee

An informal joint meeting of Unit Committee T-6R on Protective Coatings Research and Unit Committee T-6G on Surface Preparation for Organic Coatings was held at the NACE 14th Annual Conference. Various aspects of problems in surface preparation as developed mainly by work of groups in technical organizations other than NACE units was discussed.

Bigos

A new project, specifications for surface preparation, has been inaugurated by Unit Committee T-6R. The project will avoid duplication of work of Unit Committee T-6J.

Discussion at the combined meeting of the two committees was divided into six main subjects, Anchor Pattern Standards, Minimum Paint Thicknesses for Economical Protection, Painting of Rusting Steel, AWS Metallizing Test, Painting of Welds and Surface Treatment for Vinyl Coated Steel.

Anchor Patterns Discussed

E. W. Oakes, Clemtex, Ltd., explained work done toward establishing anchor pattern standards related to specific abrasive materials available in the Houston, Texas area. The question of whether to expand the investigation under sponsorship of NACE to include abrasives available in other areas, perhaps on a national scale was discussed.

On the subject of minimum paint thicknesses for economical protection, a progress report prepared by Garmond G. Schurr, Sherwin-Williams Co., was presented by Joseph Bigos, U. S. Steel Corp., committee chairman. This project was activated at a North Dakota field site. Mild steel specimens were exposed to rusting, then prepared and coated. The specimens then were exposed in various environments, Kure Beach, N. C., for marine exposure; Detroit, Mich. for industrial exposure and Fargo, N. D., for rural exposure. Problems encountered in preparing, coating and exposing specimens and the present status of the project were told.

Painting Rusted Steel

A progress report on painting of rusting steel, prepared by John Keane, Steel Structures Painting Council, also was delivered by Mr. Bigos. Purpose of the initial phase of the project was to determine the effect of inclusion of rust in paint formulation. Rust in varying proportions up to 100 percent was substituted for iron oxide in making paint. The preparations were used to coat cold rolled steel and the specimens were then exposed to varying environments. Promising data are being obtained. Apparently presence of rust in paint formulation does not promote failure of paint products. Work on other phases of the project is continuing.

In his progress report on the AWS metallizing test, C. P. Larrabee, U. S. Steel Corp., gave the objectives, information on specimens and exposure sites and presented the interim results of work on this project.

Weld Painting Studied

In another project, the painting of welds, statistical analysis of raw data obtained will be used to arrive at final conclusions. This interim report, also prepared by Mr. Keane, gave information on specimen preparation, materials and raw results obtained.

On the project of surface treatment for vinyl coated steel, Mr. Bigos discussed the application of adhesive coatings to cold-rolled steel to permit later application of vinyl plastisol to production steel to allow forming and drawing in fabrication. Problems of improving adhesion by chemical treatment of steel, and making a choice of an adhesive coating compatible with vinyl plastisol were pointed out. An estimated 30 persons attended the joint meeting.

Landers and Schremp Head Oil String Casing Unit

J. E. Landers, Continental Oil Co. and F. W. Schremp, California Research Corp. have been elected chairman and vice-chairman, respectively of Unit Committee T-1H on Oil String Casing Corrosion. The two were elected a few weeks prior to the meeting of the committee at the NACE 14th Annual Conference.

Mr. Landers joined NACE while still a student in Southern Methodist University where he majored in mathematics and chemistry. While employed by Continental Oil Co. he was called to military service in January, 1955. He served on Okinawa. On his return to the company in 1957 he reinstated his NACE membership.

Mr. Schremp received his PhD in Chemistry from the University of Wisconsin in 1950. Prior to joining the California Research Corp. in 1950, he worked for the American Steel and Wire Co. and the Manhattan project. He has been active in NACE technical committee work.

Industrial Painting Group Plans Future Activities

Discussion of plans for future work and appointment of Floyd P. Helms, Union Carbide Chemicals Co. as chairman of Task Group Committee T-6D-3 on Paint Programs were features of the meeting of Group Committee T-6D on Industrial Maintenance Painting at the NACE 14th Annual Conference. R. H. Bacon, The Dow Chemical Co. is T-6D chairman.

Task Group Committee T-6D-1 on Economics of Maintenance Painting presented a progress report. Committee T-6D-2 on Standardization of Scope of Painting Specifications, had its report ready for distribution to the committee. Committee T-6D-3 on Paint Programs, also presented a progress report.

Robert P. Suman, Pittsburgh Plate Glass Co. (Paint Div.), acted as vice chairman of Unit Committee T-6D in the absence of C. R. Martinson, Monsanto Chemical Co., the regular vice chairman. Approximately 30 persons attended.

•

In addition to those held at the annual national NACE meeting, 36 technical committee meetings were held at regional sessions during 1957.

High Purity Water Unit Schedules Literature Search

Interpretation of available literature on corrosion products and bibliographic work on the subject is the goal for 1958 of Unit Committee T-3F on Corrosion by High Purity Water, according to a report of the committee meeting held during the NACE 14th Annual Conference.

It was announced that M. C. Bloom, Naval Research Laboratory is the new vice chairman. Two task groups, one on General Corrosion, the other on Production of Water were terminated so that the parent committee could better pursue the goal for 1958. Robert U. Blaser, Babcock & Wilcox Co., is committee chairman. Mr. Bloom is corrosion consultant metallurgy division, U. S. Naval Research Laboratory, Washington, D. C. He has BS and PhD degrees from Massachusetts Institute of Technology. He has had experience in the paper and petroleum industries and has spent many years as a consultant.

Bloom

Methods of Running ASTM Rust Test to Be Surveyed

Unit Committee T-2E on Internal Corrosion of Product Pipe Lines and Tanks met under the direction of Ivy Parker, Plantation Pipe Line Co., at the NACE 14th Annual Conference.

A new project of the committee is to collect methods for running modified ASTM rust tests with an aim to making these uniform. Messrs. S. J. Artese and R. H. Brown of Shell Oil Co., discussed available methods for measuring corrosion of refined oil storage tanks.

W. S. Quimby, The Texas Co., reported on his visit to NATO pipe lines. Corrosion coupons and corrosion patterns were discussed in detail.

The proposed questionnaire on the extent of storage tank corrosion (refined products storage) was amended and the decision was made that the committee should ask the Refinery Corrosion Committee to cooperate on this program. About 20 persons attended the meeting.

San Francisco Technical—

tainment provided by the conference committee.

The charm of the city for the feminine contingent was exemplified in the registration of women, considerably more than was estimated originally. Hotel accommodations were excellent.

An opportunity was afforded during the conference for a meeting of persons concerned with the 15th Conference at Chicago in March 1959. Men responsible for this meeting made preliminary arrangements for some of the events.

An appeal for technical manuscripts to be given at the meeting was issued. Rolland McFarland, Jr., Hills-McCanna Co., Chicago, technical program chairman, wants to hear from NACE members and others interested in preparing papers for presentation at the conference.

A. B. CAMPBELL, retiring executive secretary of the National Association of Corrosion Engineers is shown here receiving from President W. H. Stewart the illuminated resolution acknowledging his services to the association. The resolution, signed by the fourteen presidents of NACE, was presented at the annual banquet Wednesday, March 19 in the Fairmont Hotel, San Francisco.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

RESOLUTION

For

ALLAN BERRY CAMPBELL

WHEREAS, Allan Berry Campbell has faithfully and diligently served the Association in the capacity of Executive Secretary since the early days of its formation, and

WHEREAS, the growth and success of the Association is due in great part to his untiring efforts, and

WHEREAS, he has consistently exerted his considerable talents of diplomacy and tact to achieve harmonious progress of the Association, and

WHEREAS, his friendliness and considerate actions have gained a host of friends for the Association, and

WHEREAS, he has been constantly aided and encouraged in the advancement of the Association by his good wife Mary Alma Campbell, best known to us as Bonnie,

Now THEREFORE be it resolved that as an indication of its sincere appreciation, the National Association of Corrosion Engineers expresses its gratitude and esteem to Berry and Bonnie Campbell and enters this resolution into the permanent records of the Association.

IN TESTIMONY THEREOF:

R. A. Brannon
President 1943-46

F. J. McElhatton
President 1946-47

G. R. Olson
President 1947-48

F. L. LaQue
President 1948-49

R. B. Mears
President 1949-50

Vance N. Jenkins
President 1950-51

Norton E. Berry
President 1951-52

M. G. Fontana
President 1952-53

Walter F. Rogers
President 1953-54

Aaron Wachter
President 1954-55

F. L. Whitney, Jr.
President 1955-56

W. F. Fair, Jr.
President 1956-57

W. H. Stewart
President 1957-58

L. L. Whiteneck
President 1958-59

Campbell Reports NACE Membership Now Over 5400

**By A. B. CAMPBELL,
Executive Secretary**

During the year, since the 1957 convention was held at St. Louis, few changes have taken place at Central Office other than the employment of additional personnel to assist in the increased amount of work incident to the growth in membership and additional service rendered, mainly to technical committees. The staff now has 27 full-time employees, an increase of three, and one part-time employee who handles our printing. This is an increase of three over the number on the staff at the same time last year. Miss Hum-

W. F. FAIR, Jr., The Koppers Co., Pittsburgh is shown handing to R. J. Kuhn, New Orleans the certificate evidencing the Frank Newman Speller Award for achievements in corrosion Engineering. Because he was unable to be present in March, T. P. Hoar, Cambridge, England will accept the Whitney Award at the 15th annual banquet in Chicago.

Plastisol coating seals out corrosion

Tank lining has built-in visual cure control

One of a group of Unichrome drum and tank lining materials, Coating B-124 is an unusual phenolic type material. When wet, it is gray in color. When fully cured, it is olive drab. This color change gives visual security against "half-baked" protection especially in large tanks and tank cars where heat application may be uneven.

Also in this coating group will be found several pigmented coatings which yield 2-mil thicknesses per coat. That's double the build-up of ordinary phenolic coatings. Obviously, fewer coats are needed, cutting time and costs.

APPLICATOR SERVICE

Specialist firms experienced in applying Unichrome lining materials are located across the country. They are well set up to handle even large equipment shipped to them. They can provide fast service, and the uniform coating with greater impact resistance and improved protection for which Unichrome Phenolic Linings are noted. Send for names.

Unichrome "Super 5300" Coating sprays seamless, pore-free lining with outstanding resistance to abrasion
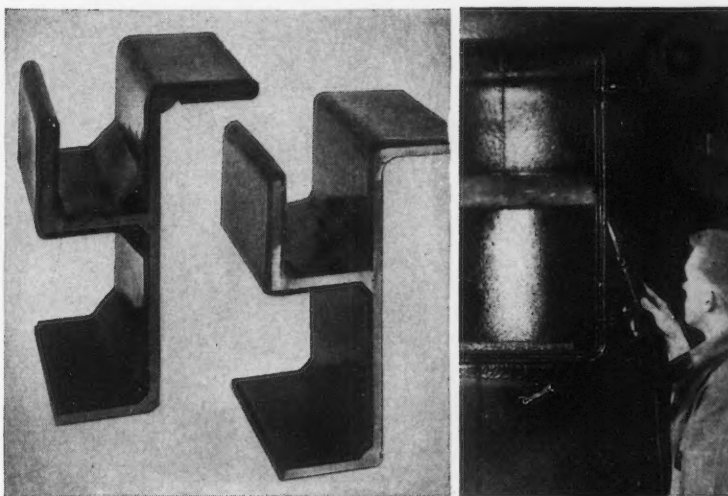
Section at left shows how sheet linings are applied, with seams at all sharp bends. Contrast this with the continuous, seamless "Super 5300" lining on section at right. There are no weak spots where solutions could undercut lining. (Far right): Spark testing of fume scrubber shown reveals no porosity in the protective "Super 5300" lining.

Chemical and corrosion engineers involved in new construction have shown keen interest in the advantages of Unichrome "Super 5300" Coating. Especially since it is a sprayable material, and can be applied up to 60 mils thick per coat to any object that can be heated to required baking temperature.

MEETS THREE IMPORTANT REQUIREMENTS

(1) Unlike usual sheet materials of rubber and plastic, "Super 5300" Coating poses no problem with seams. Since it is a liquid material, it forms a continuous coating without air pockets, eliminating potential sources of trouble, even on complicated shapes. (2) Thick and pore-free, it presents no paths for corrosive chemicals to travel to base metal. (3) It withstands abrasion and impact to a remarkable degree. Thus, it securely "seals" against corrosive attack due to penetration or to damage encountered with ordinary protective coatings.

INHERENT CORROSION RESISTANCE

A vinyl material, "Super 5300" Coating naturally resists a broad range of acids, alkalies, moisture and other active agents. Should the need arise, equipment with this coating can be patched and spot rebaked, to reform an impervious "armor" good as new.

"Super 5300" can be applied in-plant; or by expert applicators in key locations who can promptly and proficiently coat the equipment you ship them. Write Metal & Thermit for names. Or for Bulletin Chem-C-3.
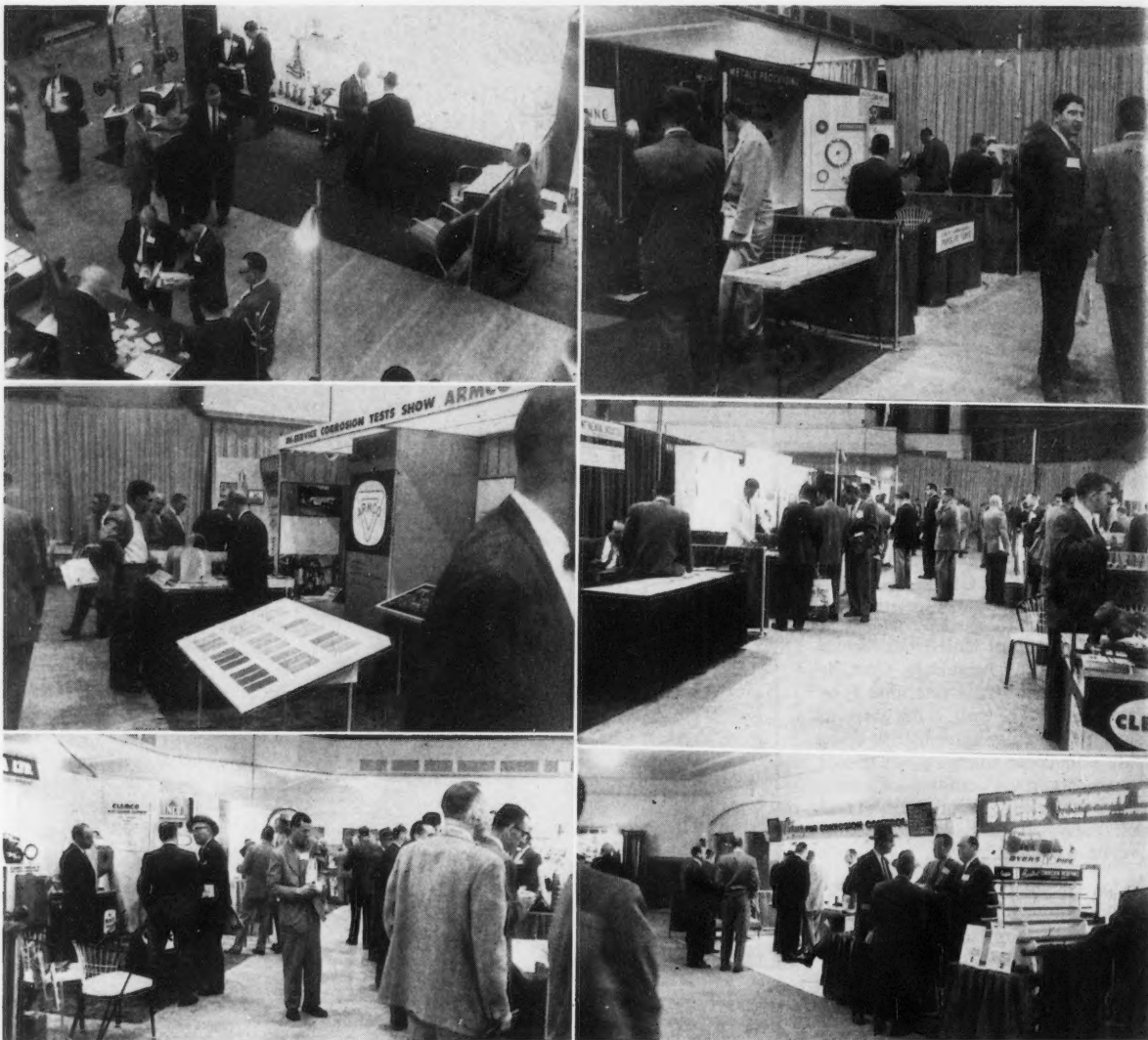
CONFERENCE EXHIBITION scenes above show a few of the interesting booths on the floor of the San Francisco civic auditorium. The 14th annual exhibition was characterized by the variety of equipment and materials usually found at NACE exhibitions.

Campbell Reports—

(Continued From Page 86)

phrey, the abstract editor, has left the association and Miss Treves has been employed to take her place.

Membership as of December 31, 1957 was 5404 active, 30 junior and 386 corporate, a total of 5820, a net gain of 360 over the total number of members on December 31, 1956. With the intensive efforts being made to obtain new corporate members, it is confidently hoped the total membership at the end of this calendar year will reach 6300.

Local Activity Important

One of the gratifying aspects of the conditions of NACE at this time is the general interest and activity of regions and sections. The six regions now have operating under them 54 sections,

all of which hold meetings periodically, several being on a monthly basis. These meetings not only stimulate interest but are a source of a great deal of technical information, much of which finds its way on up to regional and national meetings. The value to the association of these meetings cannot be over emphasized.

As to the technical committees, these too are functioning in a highly satisfactory manner. There are nine technical group committees under which more than a hundred technical unit committees and task groups have been formed, each to deal with a specific field or problem and formed in response to a specific demand. As evidence of the activity of our technical committees, more than 225,000 copies of technical committee reports were distributed in one form or another during the year.

The magazine, CORROSION, the official publication of the association, continues to serve all phases of NACE in every way feasible and practicable. There were nearly 200 more pages of editorial material in 1957 than in 1956. More manuscripts are on hand than ever before so

"Free Afternoon" for Exhibition Praised

The "free afternoon" schedule initiated for the first time during the San Francisco exhibition was favored almost unanimously by exhibitors, according to R. W. Huff, Assistant Executive Secretary and exhibits manager. The success of this experiment, in which all technical meetings were suspended for an afternoon so registrants would have time to visit the exhibition, indicates that similar arrangements will be made for the 1959 exhibition to be held at the Sherman Hotel next March.

Exhibitors were generally pleased with results, Mr. Huff said. Physical arrangements were completed with very little friction and the layout of the booths was considered satisfactory.

Van Nouhuys Heads Regional Management

Herbert C. Van Nouhuys has accepted for another year the chairmanship of the NACE Regional Management Committee.

SOME OF THE approximately 1000 persons who attended the Fellowship Hour in the Fairmont Hotel, San Francisco during the 14th Annual Conference are shown above.

Campbell Reports—

(Continued From Page 88)

the Editorial Review Sub-Committee is not pressed for suitable material for publication as it has been in previous years.

The gross paid circulation increased during 1957 by 8.5 per cent and the income from advertising by approximately 10 per cent. As publication expenses were higher, the increase of income over expenses was about 5 per cent lower in 1957 than in 1956. An increase in advertising rates that became effective January 1, 1958 has not so far indicated that our advertising will drop because of this increase.

Abstract Service Important

One of the activities of NACE that is difficult to evaluate is the abstract service. It is so vitally important to those who need this service and yet of little apparent interest to many members. Few realize the value of this service until faced with the necessity of searching the published literature for information on some specific problem. The cost of making such a search through visiting the relatively few technical and scientific libraries would be enormous while there exists, through NACE abstracts, pertinent information on more than 30,000 articles that have been published in this country and abroad since 1945. It is obvious that the savings in time and money by those in need of abstract information on corrosion literature is many times the cost now being made for this service. In spite of this useful service, we are not as yet certain that the form in which abstracts are being made available is all that it should be. Serious consideration is being given to such changes as may appear to be an improvement and within the cost and expense range of the association.

Directory to Be Published

It is not now planned to publish a Yearbook in 1958 which means that no published membership directory will be available since the one published as of June, 1957. However, a revised technical committee directory will be published and this, together with the region and section directory that is published periodically in CORROSION magazine, should serve the major need for name and address information of NACE members.

As of January 1, 1957, a pension and insurance plan for the Central Office employees became effective. This is the plan that was presented to the general NACE membership at the Annual Convention held in St. Louis in March of 1957.

It is interesting to note the increase in attention being given to corrosion in other countries. There has now been formed and put in action, the European Federation of Corrosion. A conference of this group is scheduled for Frankfurt, Germany during June of this year. The board of directors has decided that an official representative of NACE will be designated who will attend this conference and report back to our association. Also, more than one-half of the subscribers to CORROSION magazine are outside the United States, most of these going to overseas readers.

There were 292 members dropped at

Vary

hibit

offers

plasti

and v

Your

comb

LADIES ATTENDING THE SAN FRANCISCO conference are shown above at luncheon March 20 at the Fairmont Hotel, one of the events on a full program provided for their entertainment. Twice as many ladies were registered as were estimated by the conference committee, evidence of the attraction San Francisco holds for visitors.

Campbell Reports—

the end of 1957 for non-payment of their 1957 active membership dues. This compares with 274 at the end of 1956 and 347 in 1955. As near as our records reveal, there were 30 members whose death occurred during 1957. Up to March 3, there had been 103 active membership resignations thus for in 1958.

Other Items of Interest

There are other items of interest to the general membership, if time permitted their being mentioned. Most of these will be included in more detail in other reports scheduled for presentation at this meeting and not included here. However, the following might be mentioned: regional exhibits; past chairman certificates; approximately 90 have been issued; approximately 60 membership certificates have been issued.

Preparation by Committee on Education for use by sections, of a recommended plan for short courses on corrosion; preparation of list of research projects by the Committee on Research when funds for research becomes available; address and membership information that goes periodically to all region and section secretaries; need for some modernization of Central Office methods and procedures as these can be afforded by the association's financial condition.

More of the detail work of annual conventions being handled by the Central Office to relieve local members of these burdensome details; more information obtained on the facilities and conditions at annual convention sights **before** the locations are decided upon; lowering the age limit for those eligible for the Young Author Award from 36 to 30;

Preparation of handbooks for regional use by the Northeast and North Central Regions; a total of $5385 was refunded to or spent for Regions and Sections

Stegner Reports NACE Finances to Be In Satisfactory Condition as a Whole

By A. L. STEGNER
Treasurer of NACE

As a whole, NACE, finances are in satisfactory condition.

Income for the year from publications, regular business and the conference exceeded the budget slightly in each case.

Expenses for regular business were lower and for publications and the conference a little higher than the budget estimate.

In keeping with NACE growth, more money was collected than in previous years more money also was spent because there were more members.

There is a close relationship between the number of members and the money spent because the association's sole concern is its service to members.

Consistant with past operations the fiscal year ended with a small difference between income and expenses "in the black" which is added to equity. It

during 1957 from national funds; working jointly with the University of Texas on educational films on corrosion; rental of additional space in the building where the Central Office is located, for storage of publications.

I should like to conclude this report with an expression of appreciation for the help that has been given to me by the Central Office Staff, the members, officers and directors of the association and to others with whom we have dealt. The assistance of all these is deeply appreciated because it has contributed so much toward making my work pleasant. I know this same support will be given to Mr. Hull when he steps into this position. It has been a great pleasure to be associated with the NACE.

NACE Membership Growth
1958 VALUES ARE ESTIMATES

NACE Annual Income
1958 VALUES ARE BUDGET PROVISIONS

NACE Application of Funds
1958 VALUES ARE BUDGET PROVISIONS

Stegner Reports—

TABLE 1—Condensed Balance Sheet at Dec. 31, 1957

Assets

Current Assets:	
Total	$146,389
Investments:	
Shares in Savings Assns	68,000
Special Funds:	
Educational Fund	1,520
Fixed Assets-at-Cost:	
Office Furn. and Equip.	17,770
Less: Reserve for Depr.	12,051
Fixed Assets—Net	5,719
Deferred Expenses	8,724
Total Assets	$230,352

Liabilities and Association Equity

Current Liabilities:	
Total	$3,302
Amts. Rec'd in Advance:	
Total	34,740
Revenue Deferred:	
Total	22,195
Contribution for Research and Educational Purpose:	
Total	1,520
Association Equity	168,595
Total Liabilities and Equity	$230,352

took lots of hard work on the part of the president and diligent supervision and cooperation by Berry Campbell and Central Office staff to make this possible.

Figure 1 gives growth in membership.

The bottom curve representing Junior members show a loss of 1 during the year, leaving 30.

The next curve shows an increase in corporate members of 6 for the year to 386 and a projected goal of 425 for 1958. This is where a lot of work needs to be done. These important members are a vital part of the organization.

There was an increase of 354 active members to a total of 5404, with 5850 expected by the end of 1958.

The year ended with 5820 members of all kinds, with 6315 expected next year.

Figure 2 gives income for the year compared to previous years.

INCOME

Publications	$194,343
Regular Business	87,137
Conference	62,947
Total	$344,427

Figure 3 shows 1957 expenditures on the lower curve and income on the upper one. The area between the curves represents equity.

EXPENSES

Publications	$190,066
Regular Business	109,710
Conference	28,496
Total	$328,272

Income exceeded expenses by $16,156. Table 1 is a condensed balance sheet indicating a healthy financial position.

•

•

Publication Committee
Headed by R. S. Treseder

R. S. Treseder, Shell Development Co., Emeryville, Cal. has been appointed chairman of the NACE Publication Committee by President L. L. Whiteneck. Mr. Treseder succeeds T. P. May, The International Nickel Co. Inc., Kure Beach, N. C. who held the post for two years.

The publication committee, among the more active and important standing committees of the association, is charged with supervision of association publications. The committee has the following sub-committees. Abstract, Editorial Review, Advertising, Accounting and Rules.

John E. Loeffler, Thornhill-Craver Co., Houston will head the reestablished advertising sub-committee, which has been inactive for several years.

Technical Committee Cooperation Requests Growing in Number

By E. C. GRECO, Chairman
Technical Practices Committee

At the general business meeting last year at St. Louis, Mr. Larrabee reported 1956 was a year of record activity on the part of the association's technical committee. I am pleased to report that 1957 was another year of outstanding achievement. Eighty-four new committee activities were initiated, 25 committee reports were published and nearly a quarter of a million copies of technical committee reports were put into circulation.

I think you can see what this means to the association's influence and prestige. That NACE technical committee activity is becoming a widely known and a respected center of corrosion information is well illustrated by the number of requests received from other organizations for committee liaison and joint committee work. Recognition of this nature is important to the association and is essential if the association is to be the major technological organization in the field of corrosion.

You will be interested to note that the report on the NACE sponsored research project on hydrogen sulfide stress corrosion has been well received by industry. The report was published in the July issue of Corrosion and I am informed that there has been a big demand for additional copies of this report. The commitee on corrosion of oil and gas well equipment currently is looking at the possibility of a second sponsored research project. If the project is approved by the committee and the NACE board of directors it will possibly be initiated some time this year.

In general all technical committees are maintaining the high level of activity that has been characteristic of our association for the past several years.

I should like to take this opportunity to thank the officers and the directors of the Association for their cooperation and the officers of the committees for their energetic work during the past year. It has been a pleasure for me to head up the technical committees of NACE and I look forward to the next year with equal pleasure.

Problems Weighed By Policy Committee

By E. P. NOPPEL, Chairman
Policy and Planning Committee

(Part of the report submitted to the NACE board of directors at San Francisco)

A meeting of the committee was held in San Francisco Monday, March 17, 1958, at which a number of association problems having to do with policy and planning were discussed and acted upon. In view of the widespread representation, much of the committee work must be done by correspondence, and in some instances handled by the chairman.

Some of the matters given consideration and study by the committee during the past year are the following:

1. One of the group committees of the Technical Practices Committee, the T-2 Unit Committee on Pipe Line Corrosion, requested a policy opinion on a problem confronting the committee having to do with preparing minimum material requirements for pipe line wrappers.

This matter was referred to all members of the committee and, based upon opinions received from them, the chairman submitted suggestions to the president of the association.

2. In response to a request from the Awards Committee, the chairman prepared some general suggestions on the matter of awards procedure for consideration by the awards committee and copies were sent to the policy and planning committee.

3. A proposed handbook for sections was prepared by the Northeast Region to serve as a guide to operational procedure and referred to the committee for comment and suggestions, looking toward its possible use by sections of all regions.

Other matters of lesser importance were considered by the committee through its chairman, and opinions on interpretations of the by-laws and articles of organization were given to the president and executive secretary of the association from time to time as the need arose for clarification during the year. Among these matters were the following:

1. Comments were prepared having to do with membership of NACE in a corrosion organization of Brussels, Belgium—Centre Belge D'Etude de la Corrosion (Cebelcor).

2. Interpretation of the articles of organization and by-laws with respect to the office of assistant secretary of the association.

3. Suggested change in the by-laws to provide for changing the procedure for the signing of checks so that the assistant secretary might be designated by the board to sign checks.

4. Opinion in regard to the date of determining section membership in connection with a request from a section for $100 for non-reimbursable expenditures as provided in the association's procedure.

It is the desire of the chairman and every member of the committee to be responsive to the needs of the association and the committee will welcome ideas and suggestions from the membership on matters of policy and planning which will further the best interests of the association.

•

CORROSION subscribers live in over 40 foreign countries.

Active Year for Publication Committee Reported

By T. P. MAY, Chairman
NACE Publication Committee

1957 Annual Report, Publication Committee

The Publications Committee met on two occasions during the year at which most of its regular business was handled. Additional matters of business were handled by correspondence between the chairman, several sub-committee chairmen, the central office and the editor, Ivy M. Parker.

Research in Progress Series. A number of papers were provided by J. J. Harwood to be published in CORROSION as a series under the general title "Research in Progress." These items represent one activity of the NACE Research Committee.

Advertising. Advertising rates for CORROSION were increased effective January 1958 in order to take care of increased costs. It is hoped this will offset anticipated slump in revenue because of the mild business recession now in existence.

We enjoyed a 12 per cent increase in income and number of pages of advertising during the year in spite of some recession during the last quarter.

It has been the practice for Central Office to develop its own advertising program through the efforts of the managing editor. A proposal was received by the committee to consider the possibility of engaging advertising agencies on a regional basis to promote advertising for CORROSION magazine. This matter, as reported to the board, has now been taken under advisement by the Publications Committee.

In order for the committee to be more completely informed on advertising matters, it was decided to assign to one member of the committee the responsibility of following in detail all facets of our advertising problems. It was agreed that this individual should reside in the Houston area and work very closely with the managing editor on advertising matters. This assignment was accepted by John Loeffler, who has been a member of the committee for the last two years.

Corrosion Correspondents. The usual activity relative to an article each month by a corrosion correspondent has continued without any difficulties. It is expected that this activity will not change.

Cover Photos for CORROSION Magazine. The central office has expressed considerable concern over the difficulty of maintaining an adequate supply of photographs for use on the cover of CORROSION. Suggestions have been made that the Publication Committee consider using the front for indices or for advertising purposes. This matter should receive the attention of the committee during the coming year. In the meantime some concerted effort is being made to obtain appropriate photographs.

Exchange Subscriptions. The Central Office has received many requests for the arrangement of exchange subscriptions with foreign publications. The vast majority of these have not been of direct interest to corrosion engineers or have involved language and translating problems that cannot be handled by the Houston office. Accordingly, very few such arrangements were made during the year.

Release of Papers to Other Publications. Very few requests were received from authors for release of papers to journals other than CORROSION. In those cases where requests came directly from authors, the reasons for such requests were in order; and the requests were granted. A few requests were received for permission to reprint articles by companies for which authors worked. These requests were granted in accordance with our policy of requiring that such reprints include a reference to publication in CORROSION.

Abstract Card Service. Considerable attention was given to the declining interest in our abstract card service. Although NACE membership has been growing, subscriptions to our service have been slowly declining. It is believed that one of the main reasons for

Active Year—

this decline is that our cards include all topics of corrosion, whereas most users are interested in only selected portions of the cards.

Consideration has been given to the possibility of making available partial subscriptions whereby preliminary selection of the cards could be made. It has been determined that such a procedure would involve extremely costly handling of the cards by the Central Office; and, accordingly, the idea has been dropped.

The question of expenses involved in the abstract card service has received considerable attention. On the basis of a study made by the Central Office, the price per subscription was increased by the board of directors, effective January 1, 1959, from $100 to $175.

A more detailed study of the accounting relative to expenses incurred on abstract card service indicates that all of the Houston office effort that has been charged against this card service should be charged in part against Corrosion and against the bibliographic surveys, since these make use of the abstracts that are prepared for the cards. In any event the accounting system will not eliminate the fact that the abstract service is an expensive proposition.

It should be borne in mind, however, that the Publication Committee very strongly feels that this service is a most valuable one that lends considerable stature to the association and under no circumstances should it be curtailed in any way. It is desired that an effort be made to educate members regarding the value of the abstracts in the hope that they will support this activity in a more active way.

Editorial Review Sub-Committee. The review of papers that were submitted for publication was very ably handled by E. V. Kunkel, chairman and his sub-committee. In March 1957 the size of this committee was increased to over 20 members so that no one individual would be overloaded with a large number of papers for review. This has proved to be an excellent step. The committee during the year received 201 papers for review, of which seven were returned without review because they were released or withdrawn. One hundred sixty-two papers were reviewed and forwarded to the editor, of which 115 were recommended for publication and 47 recommended for rejection. At the present moment 19 papers are in the possession of authors for revision.

The chairman of this sub-committee has found it necessary to resign because of increased activity within his company. A replacement has not yet been named. This remains a very urgent matter to be handled by the incoming chairman.

Service to Corporate Members. The suggestion has been received by the Publications Committee that it consider the feasibility of providing some tangible service to corporate members in the form of subscriptions to bibliographic surveys and to the abstract card service. These items would require that the cost of the corporate membership be increased to cover the cost of such services. The matter has been taken under advisement and presumably, will be reviewed with those individuals concerned with corporate membership.

Preprints. During the past year, the committee has not had any difficulties in regard to the loss of publishable material because of the availability of preprints. During the year, there has been a continued strong pressure to have available at meetings preprints of all papers. In the past such preprints have been provided at the expense of authors who were particularly desirous of distributing them before a meeting.

Methods by which preprints of all papers can be made available to the members at meetings at nominal cost are being studied. It has been proposed that the mechanics of handling such preprints be a matter for the Central Office; and more particularly, since these preprints will be a matter of direct interest to conference committees, they should be considered as a conference item rather than a publications item. This is particularly true since preprints made available in this form will be made available without any editorial review.

Rules Committee. The Rules Committee, under the able guidance of A. B. McKee and through the assistance more particularly of the editor, Ivy M. Parker, has prepared a new guide for authors to be used in the preparation of manuscripts for Corrosion. This will be printed and made available in the very near future.

Budget and Expenses. There has been a continuing pressure on the Publications Committee in regard to the volume of material that can be printed in Corrosion because of budget limitations. It is desired to have greater freedom for publishing material which is not now being printed. It is, accordingly, brought to the attention of the readers of this report that there has been no increase in income to Corrosion from membership dues since the allocation of funds from dues was first established about 13 years ago. The Central Office has been requested to review the matter of costs of Corrosion in terms of cost per member for the years 1945, 1946 and 1947 and for 1957. On the basis of this study, the Publications Committee may ask the Board of Directors to allocate additional funds from dues to Corrosion.

At the close of the 1958 conference, the Publication Committee chairman retired because of increasing pressure of responsibilities within his company and because it was felt desirable to rotate the chair among different individuals. He was succeeded by the former vice-chairman R. S. Treseder.

The retiring chairman expresses his sincere appreciation for the assistance given to him during the year by every members of the committee, by Ivy M. Parker, N. E. Hammner, I. Humphrey, A. B. Campbell and T. J. Hull. Their assistance during the year was extremely great and is sincerely appreciated.

NACE's 1957-58 board of directors and officers are shown above at the meeting in the Fairmont Hotel, San Francisco on Sunday, March 16. Most of the members of the board are known by sight to NACE members. In the scene below some of the members of the Editorial Review sub-committee are seen at San Francisco. They are, left to right, Harry J. Keeling, Los Angeles; Ivy M. Parker, Plantation Pipe Line Co., editor of CORROSION; E. V. Kunkel, Celanese Corp. of America,

Bishop, Texas, retiring chairman; Allen L. Alexander, U. S. Naval Research Laboratory, Washington; Mark F. Adams, State College of Washington, Pullman; (standing) R. S. Treseder, Shell Development Co., Emeryville, Cal., Publication Committee chairman; John J. Halbig, Armco Steel Corp., Middletown, Ohio; Otto H. Fenner, Monsanto Chemical Co., St. Louis. Photographs at the bottom of the page were taken at the annual luncheon for corporate members of NACE.

Three Sections Added, 12,783 Attend NACE Meetings During 1957

By H. C. VAN NOUHUYS, Chairman
Regional Management Committee

During 1957 NACE added four new sections and dropped one in bettering the 1956 record. The Western Region claims the new Puget Sound and San Joaquin Valley Sections while the Canadian Region gains the Calgary Section and the South Central Region scores again this year with its latest offspring, the Panhandle Section. It is hoped that in the near future the Casper Section will receive the necessary support to justify its reactivation. Sections now number 56 as follows: South Central—15, Northeast—12, Southeast and Western tied at 8 each, North Central—7 and Canadian—6.

No sections were admitted to the "Over 100 Members" club this past year. Suggestion is made that sections having over 100 members who have not

Three Sections Added—

(Continued From Page 100)

yet made application, do so regardless of the fact that the section treasury may not now require the annual $100 gratis reimbursement. The Northeast Region now leads with five of these large sections.

Corrosion Short Courses continue to gain in popularity, totaling nine through February, which is one over last year's reported total.

12,783 Attend Meetings

The Region and Section Activities Reporting System initiated last year by the Regional Management Committee resulted in nearly 90 per cent cooperation in spite of tardy submission of quarterly reports. Based on reports received, meetings totaled 252 with attendance at 12,783 and 292 publicity items of which 45 per cent were in publications other than CORROSION.

If we attempt to obtain a fair idea of the relative activity between regions of widely varying membership by applying a "Membership Weighting Factor", we find South Central Region in first place in "number of meetings held, attendance and publicity". Southeast Region took second place for number of meetings held while the Northeast Region was second in attendance and publicity. Third place for number of meetings went to the Northeast Region, while the Canadians, in a close race, took third place in attendance from the Westerners and Southeastern breezed by easily with third place publicity.

Further breakdown of the figures is available for those interested. Two regions went to the extra effort of breaking down attendance figures into members and non-members and found that the latter comprised one-third of the total attendance. This information will no doubt be received with interest and necessary action on the part of membership committees.

Special mention goes to the most active sections in each region (no membership weighting factor used) as follows:

Region	Most Active Section
Canadian	Montreal
Southeast	Miami
Western	San Diego
North Central	Detroit (Eastern Wis. Close 2nd)
South Central	Houston
Northeast	Pittsburgh

The agenda of the Regional Management Committee this year covers such problems as:

(a) Should each region be required to maintain an up-to-date map showing its section boundaries?

(b) Should Central Office data cards to Region Secretaries be discontinued in the interest of economy and duplication, or do some regions make valuable use of this service?

(c) Should Section and Region Activity Reports be submitted quarterly as now set up, or semi-annually? And are these reports of sufficient value to warrant continuation past 1958?

(d) Approval of Section Handbook for all NACE Sections.

The Regional Management Committee invites all NACE officers to participate in its annual meeting, for only through the contribution of constructive thought and presentation of ideas in free and open forum, can our organization continue its splendid progress.

Bibliographic Surveys of Corrosion published by NACE now cover the years 1945-53 inclusive.

The NACE 15th Annual Conference and Exhibition will be at Sherman Hotel, Chicago.

Regional Management Committee Activities Report for 1957

Region	Membership	% Total	Number Meetings Actual	Number Meetings Weighted	Attendance Actual	Attendance Weighted	Publicity Actual	Publicity Weighted
Canadian	298	5.58	8	39	484	2380	1	5
Southeast	334	6.26	18	79	530	2325	15	66
Western	689	12.92	21	45	1,101	2342	7	15
North Central	1090	20.41	37	50	1,476	1986	11	15
South Central	1461	27.37	107	107	5,626	5645	137	140
Northeast	1467	27.46	62	62	3,566	3566	121	121
	5339	100.00	253	...	12,783	....	292	...

GENERAL NEWS

Aircraft and Missile Requirements Will Focus on Temperature

Astronautical vehicle progress has had a marked impact on the requirements for materials, processes, high temperature testing and manufacturing methods related to airframe and missile construction. In the "1958 Annual Survey of 5 and 10-Year Requirements" in this area compiled by the Aircraft Industries Association, Los Angeles first priority, over five years is placed on evaluation of properties from sub-zero to 1200 F of precipitation hardening semi-austenitic stainless steels. This evaluation includes corrosion resistance. Emphasis should be on consistency.

In a descending order of importance in the 5-year survey are developments related to air hardening stainless and alloy steels, aiming at tensile strengths above 300,000 psi; sandwich and panel construction, heat resistant alloys of the iron, cobalt and nickel-base type; titanium, protection from oxidation of molybdenum, development of beryllium and its alloys, limited work on aluminum and magnesium.

On the 10-year scale beryllium takes first priority for development into materials suitable for applications up to 1000 F. Next in order are development of niobium, chromium, vanadium and their alloys up to 2000 F; composite structures and single-crystal metallurgy.

Among non metallic materials emphasis is suggested on monolithic and laminated transparent materials serviceable at 700 F possessing good radiation resistance. Glass materials should be developed useful in the 1000-1200 F range and within 10 years useful at 2500 F. Laminated plastics in five years should withstand between 600 and 1000 F and have good erosion resistance.

Non-corrosive non-combustible sealants usable in the 1000-1500 F range for use in fuel tanks, fire walls and pressurized compartments must be compatible with exotic fuels. Coatings against corrosion and erosion for metallics and non-metallics should be capable of withstanding 500 to 2000 F, gaseous contamination and hot gas erosion. Fused ceramics, plating or metallics should withstand abrasion, oxidation and erosion up to 2000 F. Heat resistant coatings should be useful up to 3500 F and for certain applications up to 6500 F.

Non-corrosive hydraulic fluids resistant to fire and nuclear contamination are needed.

High Flux Reactor Critical

A new high flux research reactor went critical March 21. Designated Oak Ridge Research Reactor (ORR) it is a high-flux, tank-type reactor immersed in a pool to be used for fundamental research and engineering studies on the effect of nuclear radiation on reactor materials. It is operated by Union Carbide Corp. for the U. S. Atomic Energy Commission.

BOOK NEWS

Engineering College Research Review, 1957. 408 pages, 6 x 9 inches, paper. 1957. Engineering College Research Council, New York University, University Heights, New York 53, N. Y. Per copy, $2.

A survey of research in institutions, including armed service schools, colleges and universities, arranged by institutions. Among the data given for each institution are mailing address, names of responsible officials, policies, personnel, expenditures, income, lists of short courses and conferences, lists of research projects. Lists of research projects previously scheduled and now in progress are listed by subject matter. An alphabetical subject index is included.

Nickel and Its Alloys. NBS Circular 592. 87 pages, 7⅞ x 10¼ inches, paper. Feb. 5, 1958. Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Per copy, 60¢.

A revision of Circular 485 (1950) comprehensively covering the origins, refining, uses and properties of nickel. About 800 references are listed. The revision was sponsored by The International Nickel Co., Inc., under the National Bureau of Standards' research plan.

Stainless Steel Fabrication. 384 pages, 7½ x 10½, Cloth. 1957. Allegheny Ludlum Steel Corp., Advertising Dept., Oliver Bldg., Pittsburgh 22, Pa. Free, on letterhead request.

A comprehensive exposition, illustrated and printed in two colors of the fabrication of Allegheny Ludlum stainless steels. Data presented are the product of over 30 years of work and investigation and represent the best available information. The purpose of the book is to aid and guide those now engaged in and those who will be engaged in handling stainless steel fabrication.

Some data are given on corrosion resistance specifically, in which standard analyses are rated against a list of corrosives. However, because of the importance of corrosion resistance, details of many techniques include instructions on ways to avoid corrosion damage, although they are not so identified. There is an alphabetical subject index.

The profuse and clear illustrations and tables of data make the book excellent for reference purposes.

Symposium on Determination of Dissolved Oxygen In Water. 59 pages, 6 x 9 inches, hard paper, 1958. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. ASTM Special Technical Publication 219. Per copy, $2.25.

Consists of the five papers presented at the named symposium on June 20, 1957 at Atlantic City, N. J. and the discussions related to these papers. Subjects covered are accuracy of testing methods, polarographic measurements, Beckman dissolved oxygen analyzer, evaluation of Hartmann and Braun recorder for boiler

feedwater and determination by means of Cambridge analyzer.

Plant Design and Economics for Engineers. 511 pages, 6 x 9 inches, cloth. January 2, 1958. By Max H. Peters. McGraw-Hill Book Company, Inc., 330 West 42nd St., New York 36, N. Y. Per copy, $11.

A discussion of economic and design principles applied to chemical engineering processes and operations. Orientation is thoroughly economic with topics covered including, costs in chemical processes, interest and investment, depreciation, cost and asset accounting and others. It is extensively illustrated.

Corrosion is not considered separately from other maintenance and obsolescence factors. There is no subject indexing of corrosion.

Dislocations and Mechanical Properties of Crystals. 634 pages, 6 x 9 inches, cloth, 1957. John C. Fisher, editor. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. Per copy, $15.

Proceedings of an international conference held at Lake Placid, N. Y. September 6-8, 1956 sponsored by Air Force Office of Scientific Research, Air Research and Development Command and the General Electric Research Laboratory. The papers were presented at a closed conference by a selected group of specialists in the field of mechanical aspects of dislocations. The discussions were recorded and edited for this volume.

Included are 42 discussions under the following headings: Direct observation of dislocations, deformation of pure single crystals, work hardening and recovery; alloy crystals, impurities and yield point phenomena; dislocation damping and fatigue, theory of dislocations, whiskers and thin crystals, radiation damage. The book is extensively illustrated with photographs, diagrams and graphs related to the material. Appropriate references are appended at section ends.

There is an index of contributors and an alphabetical subject index.

Industry Fights Corrosion. 107 pages, 8¼ x 11¼ inches, paper. 1958. Corrosion Technology, Stratford House, Eden St., London N.W.1. Per copy, 21 s.

Thirteen papers presented during the "National Anti-Corrosion Week" convention organized by Corrosion Technology magazine and the Leonard Hill Technical Group. Discussions related to each paper are included.

Topics covered include organic and metallic coatings, shipping industry, packaging, water treatment, atomic energy, fuel additives, mate metals and alloys, cathodic protection.

Turbine Uses Waste Gas

A gas turbine burning waste gas given off by steel mill blast furnaces was described at the Third Annual Gas Turbine Conference and Exhibit at Washington D. C. by Z. S. Stys, president of Brown Boveri Corp., New York.

Titles Changed on Library Of Congress Publications

Changes have been made in the titles but not in the contents of two Library of Congress publications. The new "Monthly Index of Russian Accessions," formerly was titled "Monthly List of Russian Accessions." The new "East European Accessions Index" formerly was titled "East European Accessions List."

Each index gives in English a monthly account of new material in a variety of subject fields from USSR and Eastern Europe received by the Library of Congress and other American research libraries. Translation of all book titles and articles into English and elaborate subject guides permit a researcher to easily identify material interesting to him. In Volume 9 of the Monthly Index of Russian Accessions, 54 percent of the books and periodicals were in the field of science and technology.

The East European Accessions Index, published monthly, lists and annotates publications received by the Library of Congress and more than 100 major research libraries in the United States and Canada from Albania, Bulgaria, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Poland, Rumania and Yugoslavia.

Both publications are available from the Government Printing Office. Monthly Index of Russian Accessions sells for $12 a year ($15 abroad); East European Accessions Index sells for $10 a year ($12.50 abroad).

Corrosion Papers Scheduled At Nuclear Conference

Numerous papers on corrosion and related topics were presented during the March 17-21 4th Nuclear Engineering and Science Conference at Chicago. Included among them were:

Location of Leaks with Radioisotopes in Multiwalled Tanks, W. F. Sullivan and J. R. Coleman, National Lead Co.

Corrosion Behavior of Uranium-Zirconium Alloys in High Temperature Water and Steam, S. Kass, K. M. Goldman, and D. E. Thomas, Westinghouse Electric Corp.

Corrosion Behavior of Uranium-Niobium Alloys in High Temperature water, J. N. Chirigos, J. Hino and J. J. Lombardo, Westinghouse Electric Corp.

High-Temperature Fatigue Testing—With Application to Uranium by Jack R. Bohn and Glenn Murphy, Iowa State College.

Corrosion Screening of Component Materials for NaK Heat Exchange Systems, Samuel J. Basham, John H. Stang and Eugene M. Simons, Battelle Memorial Institute.

Dynamic Corrosion Tests of Materials in Irradiated Organics, H. Kline, N. J. Gioseffi and W. N. Bey, North American Aviation Co.

Radiation Damage Studies of Seven Non-Fissionable Metals, C. A. Bruch and W. E. McHugh, General Electric Co.

Radionuclides in Reactor Cooling Water—Identification, Source and Control, Dade W. Moeller, Robert A. Taft Sanitary Engineering Center; George W. Leddicote and Sam A. Reynolds, Oak Ridge National Laboratory.

Facilities to Study the Effects of Radiation on Petroleum Processes and Products and the Uses of Radioactive Materials in the Petroleum Industry, R. J. Buehler, Sinclair Research Laboratories, Harvey, Ill.

The Bettis Plant Radioactive Sample Corrosion Tests Facility, A. L. Maharam, Westinghouse Electric Corp.

Corrosion in Petroleum Industry on ASTM Agenda

"Corrosion in the Petroleum and Chemical Industries," is the title of a symposium to be given May 15 during the American Society for Metals' Southwestern Metal Congress, Dallas, May 12-16. P. L. Willson, Halliburton Oil Well Cementing Co., Duncan, Okla., and J. C. Spalding, Jr., Sun Oil Co., Dallas, are chairmen.

Scheduled are papers on Cost of Corrosion and Economics of Materials Selection; Corrosion Resistant Alloys.

Metallic Coatings for Corrosion Protection, John Eggleston, Vapor Honing Co., Houston.

Non-Metallic Coatings for Corrosion Protection, L. E. Edgar, Tube-Kote, Inc., Houston.

High Temperature Corrosion Problems.

Cathodic Protection—Principles and Application.

Importance of Inspection in Corrosion Control. R. M. Ives, Jr., Humble Oil & Refining Co., Houston.

Technical Translations of Soviet Orbit Data to Be Available From Institute

Results of scientific and technical developments in Russia and Soviet-orbit countries will be made available through the Pergamon Institute, a non-profit foundation for the furtherance and dissemination of scientific knowledge. Its domiciles are Washington, D. C., and London, England.

The institute will perform several functions: Translate into English Russians books and technical articles. Discover new ways to increase dissemination of Russian and Slavic technical knowledge among English-speaking scientists. Encourage the study of Russian as an extra-curricular activity in the science, medical and engineering faculties of colleges and universities. Review bibliographically Russian technical progress 1920-56.

The institute already publishes translations of a number of Russian journals, including Atomnaya Energiya, Elektrichestvo, Physics of Metals and Metallurgy, Abstracts of USSR Metallurgy.

Additives for Low Grade Fuel Oil Are Discussed

Anti-corrosion additives for low grade fuel oil used in gas turbines may be used either dissolved in the oil, as insoluble powders or as liquids, according to R. C. Amero, A. G. Rocchine and C. E. Trautman, Gulf Research and Development Corp., Harmerville, Pa. in a paper at the Third Annual Gas Turbine Conference of ASME in Washington. Their tests showed micronized talc, magnesium oxide and potassium permanganate effectively reduced corrosion at costs ranging from less than one cent to about 11 cents a barrel of oil.

Synthetic sea water and other materials containing sodium or potassium also reduced certain types of corrosion and enhanced effectiveness of other inhibitors.

ASTM Studies Cermets

A study commitee on cermets was authorized by American Society for Testing Materials during the February Committee Week in St. Louis. The committee will analyze the present status in industry and make recommendations on how proper standards may be devised.

Nuclear Reactor Course

"Materials for Nuclear Reactors," is the title of a one-week course offered by New York University during the summer of 1958. The College of Engineering's fourth annual titanium meeting will be held September 8-9.

Equipment Services   NEW PRODUCTS   Materials Literature

Aluminum

Aluminum-clad transit cargo buildings for salt-water port facilities have been constructed at Port Newark, N. J. Each building is 880 feet by 200 feet. Aluminum Company of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa., says aluminum was selected because of low maintenance, high resistance to corrosion, pleasing appearance and long life.

●

Kaiser Aluminum & Chemical Corp., 1924 Broadway, Oakland 12, Cal., has provided the materials for making an all-aluminum 42-foot work boat for heavy duty on the Willamette River in Oregon. The boat weighs half as much as it would if made of steel and has a draft of several inches less. Bimetallic corrosion between the aluminum structure and the steel shafting and babbitt bearings was prevented by use of stainless steel and rubber liners, gaskets and bearings all of which are commercially available.

Bolt Torque Data

The Skidmore-Wilhelm Mfg. Co., 442 South Green Rd., South Euclid, Ohio has published a special report explaining distribution of torque on nuts and bolts when they are tightened and other information on torque and proper selection of bolts, nuts and washers.

Clad Materials

General Plate Div. of Metals & Controls Corp., Attleboro, Mass., has published a new bulletin on platinum-clad metals, PLA-5. Platinum clad is available as a single overlay, double clad, edgelay, top-lay or inlay. Precious metal is saved and mechanical strength, electrical and thermal conductivity, and wear and hardness qualities are provided.

●

Chicago Bridge & Iron Co., 332 S. Michigan Ave., Chicago 4, Ill., has published a 32-page brochure describing the manufacture of Hortonclad, a composite metal produced by a flux-free high strength bonding process which provides an integral and continuous bond between an alloy or special metal and its backing plate. Lists of materials available and a description of the firm's facilities are included.

Coatings—Organic

Bakelite Co., Division of Union Carbide Corp., 655 Madison Ave., New York 21, N. Y. has developed a one-coat maintenance paint for use on porous concrete and a variety of metals without costly surface preparation. A test showed only one coat was required for adequate hiding and protection. Cost of application was slightly more than half that of other jobs requiring two coats.

●

Lucey Export Corp., New York has been named export sales representative for Tube-Kote, Inc., Houston, Tex., in Brazil and Argentina. Tube Kote applies baked phenolic coatings to oil field tubular goods for prevention of corrosion and paraffin deposition. Plants are located in Houston and Harvey, La.

●

The DeVilbiss Co., Toledo 1, Ohio, is accepting applications to attend its spray painting school. Subjects covered are industrial product finishing, maintenance painting, general refinishing, service training, automotive jobber and portable equipment. The school is free to owners or sellers of DeVilbiss equipment or their representatives or operators. For information write the company's educational department.

●

Coatings for Concrete, developed by the Hodges Chemicals Co., Redwood City, Cal. are designed to protect surfaces for years against pitting, breaking and erosion. The two new 100 percent solids epoxy-based coatings are used in food processing plants, canneries and chemical plants where corrosives have damaged concrete floors.

●

American Chemical Paint Co., Ambler, Pa., has published Bulletin 1424-A about its line of protective and prepaint coating chemicals for aluminum. The booklet discusses advantages of the coatings, methods of application and equipment used and lists type of metal product treated and includes a convenient selection chart.

●

Bakelite Co., Division of Union Carbide Corp., 655 Madison Ave., New York, N. Y. is conducting long-range tests on water-based latex paint for outdoor use on some 20 houses and buildings across the United States to determine the resistance of this paint to a variety of climatic conditions. The firm has developed latex paints for outdoor use which, it maintains, offer advantages of application, appearance and performance over others.

Fittings

Cosasco Division of Perfect Circle Corporation, El Monte, Cal. is offering a new 32-page catalog covering its complete line of access fittings for oil wells, pipe lines, refineries and industry. The fittings allow access under pressure to interiors of oil wells, pipe lines and other pressure vessels for corrosion surveys and other purposes.

Heat Exchangers

Alcoa Expandable Tube-Sheet, made by Aluminum Company of America, 732 Alcoa Bldg., Pittsburgh, Pa. is made by a revolutionary process for producing tubular shapes within sheet and plate. The new method employs a one-piece unit of aluminum sheet, or plate, containing a series of lengthwise, parallel areas that can be expanded easily to form integral tubing. The product is exceptionally suited to solve heating and cooling problems found in many industrial processes and can be used to circulate liquids or gases within leakproof enclosures.

Inhibitors

Du Pont's Fuel Oil Additive No. 2, when added to residual fuel oil tanks acts as a stabilizer, solubilizer and dispersant and helps prevent sludge formation. In one case, use of $20 worth of the additive saved $800 over costs of mechanical de-sludging and cleaning, according to du Pont de Nemours & Co., Wilmington, Del.

●

Calgon Composition TG, a sodium-zinc hexametaphosphate corrosion inhibitor for municipal and industrial water systems, is described in a new bulletin issued by Calgon Co., 323 Fourth Ave., Pittsburgh. The compound is said to provide a fast forming, protective film on metal surfaces and to be effective at low concentrations.

Instruments

Gulton Industries, Inc., 212 Durham Ave., Metuchen, N. J. has patented a new soldering iron which, in addition to heat, employs ultrasonic vibrations to eliminate the use of flux in soldering such materials as aluminum, and magnesium and their alloys. It is particularly useful where the corrosive effects of flux must be avoided.

●

Two new thermostat switches, designed to resist corrosion have been developed by Fenwal Inc., Pleasant St., Ashland, Mass. Temperature range of the stainless steel switches is —100 to 600 F. They are field adjustable. Corrosion resistance to acetic acid vapors, 5 percent sulfuric acid (up to 120 F) and many other salts and acids is claimed.

●

Continental Oil Co. has contracted for use of an electronic computer-data processing system designed to sustain peak operational efficiency in a catalytic reformer producing some 10,000 barrels of high-octane gasoline a day. Production yields and other operating statistics essential to optimum process control will be computed automatically. The Systems Division of Beckman Instruments, Inc., 325 N. Muller Ave., Anaheim, Cal. was given the contract for the computer service.

●

Sensitive Research Instrument Corp., 310 Main St., New Rochelle, N. Y., makes a Reference Standard Heavy Current DC Ammeter with ranges from 1 to 100 amperes and accuracy of two-tenths of one percent. It is available in a self-contained unit.

Metals—Non-Ferrous

The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y., has developed a new process for electrorefining nickel. A main feature of the process is the direct electrolysis of nickel matte, an artificial sulfide. It eliminates high-temperature oxidation and reduction operations with attendant losses of metals and sulfur and selenium and makes pos-

NEW PRODUCTS

(Continued From Page 105)

sible commercial recovery of elemental sulfur and selenium.

Cadmium strip and foil rolled to thicknesses as low as .005-inch is now in commercial production at the plant of the American Silver Co., 36-07 Prince St., Flushing, N. Y. Suggested uses are in packaging to provide very high corrosion protection; in electronics, for electrical contacts and printed circuitry and in nucleonics, wherever high neutron absorption properties are needed.

Tube Turns, a division of National Cylinder Gas Co., plans to offer a complete line of welding fittings and flanges of commercially pure grades of titanium to match schedules and sizes of titanium piping now made.

Metachemical Processes Ltd., Crawley, England, have developed **Micrograin** nickel, a new type of material which is extremely hard, yet flexible. Resistance to abrasion and impact are unusually high. Brinell hardness is up to 600, yet the material may be bent easily without fear of cracking. Agents for the manufacturers are Dalic Metachemical Ltd., 121 Judge Rd., Toronto 18, Ont., Canada.

Non-Metallics

NF-X, a new film with exceptional corrosion resistant properties has been discovered by chemists of Joclin Manufacturing, Wallingford, Conn. The material resists such corrosives as fuming red and white nitric acid, hydrazene, aluminum trimethyl and hydrogen peroxide for long periods, with no leakage or deterioration. It is used in bladders, tank liners and pressure equalizers. Storage tests lasting three months show no damage to the containers which are made without seams. Recommended service temperature ranges are from 100 F to 400 F. Intermittent use at 600 F produces no failures.

Nuclear Fuel

Sylvania-Corning Nuclear Corp., Bayside, Long Island, N. Y., has announced a nuclear "package fuel" plan under which the firm will deliver the completed nuclear fuel unit to the customer, obtaining all fuel materials and delivering finished core loadings under a single fixed price.

Plastics

Carl N. Beetle Plastics Corp., 145 Globe St., Fall River, Mass., has published four illustrated data sheets outlining corrosion resistant processing and storage equipment. The company makes Beetle Bonate vents, ducts, hoods, pipes, fittings, recovery tanks and like equipment.

Southwestern Plastic Pipe Co., Box 117, Mineral Wells, Tex., has issued a 4-page illustrated folder which describes uses of three types of semi-rigid and rigid plastic pipe. Southwestern also manufactures polyethylene flexible coil pipe, drainage pipe, well casing and conduit.

L. A. Darling Co., Plastics Div., Coldwater, Mich., has published a free brochure on fiberglass, corrosion-resistant linings for industrial tanks. Strength, lightweight construction and high insulating qualities combine to reduce maintenance and production costs, the firm states.

Tube Turns Plastics Inc., Louisville, Ky., has replaced its existing line of smooth-face flanges with a complete line of flanges with concentric-serrated faces for polyvinyl chloride piping systems. Better gasket retention, a more effective seal and improved appearance were given as advantages of the new design.

W. R. Grace & Co., Polymer Chemicals Div., Clifton, N. J., has published two new booklets: "Molder's Guide to Injection Molding GREX High Density Polyethylene," and "Fabricator's Guide to Extruding GREX High Density Polyethylene." The first book describes fundamental molding characteristics with recommendations for mold design. The second gives techniques for manufacture of film, sheet, tubing, profiles and shapes.

Duracor reinforced plastic, made by the Ceilcote Co., 4874 Ridge Rd., Cleveland 9, Ohio, is being used to fabricate gas scrubbing towers capable of resisting the highly corrosive gases and extreme temperatures encountered in the chemical and metalworking industries. The material combines high strength, design flexibility, easy workability and resistance to most corrosive gases, fumes or liquids.

MEN in the NEWS

William J. C. Marshall, Jr. is general market sales representative for the New England states and **C. E. Boston** holds the same position for Northern California and Western Nevada for Dresser Mfg. Div., Bradford, Pa.

Joseph V. Petrocelli has been appointed head of the Electrochemical Section of the International Nickel Company's research laboratory at Bayonne, N. J.

Robert A. Kokat has been appointed branch manager of The Carpenter Steel Company's Philadelphia operations.

Gerald R. Garinger has been appointed assistant branch manager of the company's Toledo, Ohio mill-branch warehouse.

H. F. Jacobsmeyer has been named sales manager of Grayson Controls Division, Robertshaw-Fulton Controls Company. Mr. Jacobsmeyer, formerly district sales manager for Grayson Controls, replaces **A. W. Beck** who was named marketing vice president for the company.

Rosemarie Meyer has joined Wright Chemical Corporation's research department staff as a microbiologist. She formerly was employed by an air conditioning equipment manufacturing firm in its quality control department.

Neil J. Culp and **Samuel M. Purdy** have been promoted by the Carpenter Steel Co., Reading, Pa. to supervisory posts in the metallurgy department. Mr. Culp as supervisory metallurgist-alloy development, is responsible for research and development on tool and alloy, high temperature alloy, stainless and magnetic alloy steels. Mr. Purdy as supervisory metallurgist-metallography is in charge of metallographic and crystallographic activities of the Carpenter Research Laboratory.

D. A. Mitchell and **W. D. Labaugh** have been promoted district managers of industrial tar products sales. Mr. Mitchell will cover the Western part of the U. S., with headquarters in Chicago. Mr. Labaugh will handle sales in the Eastern part of the country, with offices in New York City.

Leave of absence has been granted **Lambert L. Lind, Jr.** from Ebasco Services Inc. so that he might work with the U. S. Department of Defense. He is now special assistant to Roy W. Johnson, director of the Advance Research Projects Agency which was established recently to meet the needs of the nation's space conquest program. Mr. Lind was principal electrical engineer witth Ebasco's design and construction division.

John J. Buckley is the newly appointed vice president in charge of all company divisions of J. Bishop & Co., Malvern, Pa. He will continue to serve in his capacity of general operations manager for all company plants.

William A. Reich has been named manager of the Engineering Section of General Electric Company's Metallurgical Products Department in Detroit. He will be responsible for all Carboloy cemented carbide engineering operations of the department, including engineering consultation, administration, advance engineering, applied mechanics, products design and products development.

Frederick J. Close has been named general manager of the sales development and commercial research divisions of Aluminum Company of America.

Charles M. Beeghly has been elected executive vice president of Jones & Laughlin Steel Corp. He is also a director of Jones & Laughlin.

Marc Darrin, former associate director of research for the Mutual Chemical Company of America, has retired after 40 years in the chemical industry. He is author of more than 100 published articles on a wide variety of chemical subjects, and holds more than 50 U. S. and foreign patents. He is a member of National Association of Corrosion Engineers and served on the association's editorial review sub committee.

Ed J. Baudoin joined Odis Galloway Co., Inc. recently as sales engineer, representing the firm in Louisiana. The firm applies internal and external coatings of plastics on tubing, pipe and other equipment, specializing in petroleum industry work.

Ottmar M. Tishlarich and **George M. Schaefer,** two veteran employes of A. M. Byers Co. have retired. Mr. Tish-

MEN in the NEWS

larich was assistant to the general superintendent and plant engineer at the Company's Pittsburgh plant, and Mr. Schaefer was night superintendent at the same plant.

Ira Kukin is now research director at the Belleville, N. J. plant of L. Sonneborn Sons, Inc. In his new position he will be in charge of research and development on petroleum and textile products for the company.

R. A. McNeilly is now works manager for Tube Reducing Corp., Wallington, N. J. Plants under his supervision make Niphos-process corrosion resistant coatings and manufacture "Rockrite" cylinder-finish seamless tubing.

W. F. Munnikhuysen, retired from the chairmanship of the board of directors of Koppers Co., Inc., Pittsburgh, Pa., at the age of 65. He will remain as a member of the board and will continue as a consultant. He is succeeded by **Fred C. Foy** who will hold the dual position of chairman of the board and president of the company. Mr. Munnikhuysen has been with the company since 1916. Mr. Foy joined Koppers in 1948 as vice president and manager of the headquarters sales department. The company has formed two new divisions. **David L. Eynon, Jr.** will become vice president and general manager of the new plastics division, and **T. C. Keeling Jr.** will hold the corresponding position heading the new chemicals and dyestuffs division. Koppers has only recently put into operation a plant to make high-density polyethylene and a new plant to make expandable polystyrene will go into operation shortly.

Donald R. Meserve, product manager of organic coatings at Metal & Thermit Corp., was recently elected chairman of the Vinyl Dispersion Division of the Society of the Plastics Industry, Inc. The group is working with the National Bureau of Standards and the American Society for Testing Materials to develop standard test procedures used in determining the quality and characteristics of such dispersions.

Ed L. Dressel, of the Tretolite Co., division of Petrolite Corp., has been assigned to head the company's new field service laboratory recently completed at Odessa, Texas.

Miro A. Grottger has joined the Industrial Finishes Co., Philadelphia, as vice-president and director of research. Mr. Grottger is the developer of a protective and decorative coating for conduit for carrying wire. The hard smooth coating is corrosion resistant and facilitates insertion of the wire in the conduit. He has had extensive experience in education and technical societies.

Warren K. Brown, Alan T. Canham, and **Lee W. Douglas** have received promotions with Chemical Linings, Inc., Watertown, N. Y. Mr. Brown has been named chief engineer for the firm. Mr. Canham has been appointed assistant to the president. Mr. Douglas has been appointed manager of Chemical Linings de Mexico, S. A. de C. V.

Alfred T. Daech has been named group leader in the research and development laboratory of the Carboline Co., St. Louis, Mo. This group is engaged in development work on surface coatings with vinyl and urethane materials.

Lawrence H. Bennett has joined the metal physics section of the National Bureau of Standards' Metallurgy Division as the leader of a project concerned with fundamental investigations of the electronic properties of metals.

Ross L. Gilmore, president of the Superior Steel & Malleable Castings Co., Benton Harbor, Mich., took office as president of Steel Founders' Society of America for the 1958-59 term at the 56th annual meeting of the society held at the Drake Hotel, Chicago, Ill., March 17 and 18.

Frank Bright has been appointed sales manager of Standard Magnesium Corp., Tulsa, Okla. He had previously been sales manager for another firm and prior to that was on the faculty of the University of Tennessee. Standard Magnesium Corp. makes magnesium anodes for corrosion protection.

Roy D. Super is now industrial sales representative for Napko Paint Corp., according to an announcement by **J. E. Rench,** vice-president of the firm. As a technical representative he will consult with industries on proper paint application, Mr. Rench said. Mr. Super and Mr. Rench are members of NACE.

Surface Preparation Is Key To Coatings Life On Underwater Structures*

Abstract

Sand-blasted surfaces inhibited by phosphoric acid or wash primers extend from one or two years to five or six years the life of coatings applied to the upstream side of sluice gates in Susquehanna River water. Tests over more than 20 years using various surface preparation and application methods and almost every known type of coating indicate best service (10 years) is achieved from a system using sand-blasted surfaces, phosphoric acid inhibition and a phenolic base, zinc dust-zinc oxide paint and a modified alkyd base red lead paint. It is desirable, however, to metallize rivet heads before painting.

Tests with vinyls started in 1945 indicate these materials give results as good as the metallized-phenolic-alkyd combination, even on rivet heads. Vinyls have bright future for this type of service.

Check on application methods indicate hot spray has merit and that coatings applied by roller are as good as brushed or sprayed coatings, especially around rivet heads.   5.4.5

MORE THAN 20 years' experience on riveted steel flood gates proves that good surface preparation is a basic prerequisite to satisfactory coating performance.

This truism is illustrated by experience in 1931-34 with 32 sluice gates each having 1800 square feet of exposed surface upstream. These gates were painted with a linseed oil base red lead shop coat, a second coat of red lead and final coat of a cheap bituminous product after cleaning with mechanical brushes. By 1934 all gates were severely pitted so a test was made of 30 so-called superior products. Few synthetics were available then. After a year, no trace of any of these coatings could be found on the gate surfaces exposed to trash, wave action and pack ice in Susquehanna River water.

Sand-Blasting Is Tried

Because surface preparation in the tests had been by mechanical wire brushes and scrapers, it was decided to try sand-blasting. This brought encouraging results in the form of three and four year life for coatings which formerly disappeared in one year.

Although this improvement was welcomed, further tests were made in 1941 in which sand blasted surfaces were treated with a phosphoric acid base inhibitor. This further improved service with some types of coatings. The combination of sand-blasting and inhibition increased to five to six years the service life of coatings which formerly had lasted only one to two years.

Serious Testing Started

Following a conference with experts on coating problems in 1937, several systems recommended by experienced engineers were tried without success. Since that time an expanded program, using different surface preparation methods and materials has brought under test almost every known type of coating. Few of these can be rated as entirely satisfactory for the service.

At one time, when the problem seemed impossible of solution, tests were started on applying stainless clad plates to the gate surfaces. While the material proved satisfactory, the cost was prohibitive, compared to organic coatings.

Experiments were started in the late 1920's with sprayed metallized zinc on trash screens at the Holtwood plant of the Pennsylvania Water and Power Co. Very poor results were obtained and further use was abandoned. In 1935, however, because the method of metallizing had been improved, a test panel with 0.010-inch of zinc was exposed and after two years it looked so promising that an entire 1800-square-foot surface on one flood gate was sprayed.

Galvanic Corrosion Stopped

After several years' exposure it was learned that failure of the metallized zinc coating in the vicinity of the vertical bronze gate seal could be stopped by applying a synthetic coating for a distance of four feet over the zinc adjacent to the seal.

Because the ultimate life of the metallized surface was not known and because of the relatively high cost of the application, search continued for better materials. After 13 years of testing it was learned that a phenolic base, properly proportioned zinc dust-zinc oxide paint and a modified alkyd base red lead paint provided almost complete protection against corrosion for 10 years when applied over sand-blasted and in-

TABLE 1—Analysis of Painting Costs on Riveted Floodgate

(Gate measures 50 x 36 = 1800 sq. ft., upstream side only)

Item	TOTAL COST IN DOLLARS		
	Material	Labor	Total
Sandblast	$ 90	$260	$350
Inhibit	15	35	50
Paint-3 coats sprayed	65	135	200
Miscel*	10	40	50
Total	$180	$470	$650
Percent Total	28	72	100
	COST PER SQ. FT. SURFACE		
Sandblast	$ .05	$ .145	$ .195
Inhibit	.008	.020	.028
Paint-3 coats sprayed	.035	.075	.110
Miscel*	.006	.022	.028
Total	$ .10	$ .26	$ .36

*Metallizing of rivet heads is included in miscellaneous.

This analysis covers a total of 26 gates or 46,800 sq. ft. of surface painted over a period of 13 years. The costs are based on present day prices for material with labor cost figures at an average of $2.00 per hour. No charge is made for compressed air used for blasting or painting. At an average 10-years' service, the cost per flood gate is only $65 a year.

hibited surfaces. Neither of these products, however, protected rivet heads for more than five years.

When the rivet heads are zinc metallized, protection for 10 years is achieved. Because of this a procedure was adopted whereby all rivet heads were metallized before application of the coatings, regardless of painting methods. The combination of metallizing and coating system then made possible a maintenance program requiring painting of only three gates a year.

Vinyls Prove Best

Twelve years of exposure of vinyl protected surfaces have proved that these materials are as good protection for rivets as metallizing. In 1945 a vinyl-type system consisting of one prime coat (not a wash primer) was brush applied and four body coats and two seal coats were applied by spray over 250 square feet. Although costly at that time, this has proved in the 12 years since to be highly satisfactory protection.

Tests have been expanded to compare vinyl-protected and metallizing-protected rivet heads. Improved materials, application methods and lower costs in the years since indicate vinyls have a bright future. It is believed they may change the whole painting procedure on the sluice gates because multiple coats can be applied in a single day and under much more adverse weather conditions than with phenolics.

Experience has shown that fast drying paints require best weather conditions, better surface preparation and proper timing of application of successive coats. If more than 24 hours elapses between the second and third coats the top coats have a tendency to peel. This is true especially of the phenolic zinc dust-zinc oxide. By adding up to 3 percent by volume of solvent to the second and third coats (about the maximum possible to avoid sagging) this tendency is overcome.

A phosphoric acid type inhibitor or wash primer used on a cleaned surface protects it so it is possible to wait for

Surface Preparation—
(Continued From Page 111)

satisfactory weather to apply the remaining coats. Experience has proved that warm, dry weather is essential and that painting in the area covered in this article should not begin before 10 am or extend after 4 pm, especially when using phenolics or alkyds.

Application Methods Watched

While experimenting over the years with various types of coatings, systems and application methods, close watch was kept on the relative merits of the various means whereby coatings are transferred to the surfaces. Inspections of the gates revealed, for example, that brush application generally was superior overall to spray application, but not so much so that its superiority outweighed the higher cost of brush application.

However, it was demonstrated that brush application on rivet heads gave better protection than spray so during spray application a man follows the spray with a brush at each rivet to eliminate the bridging tendency of coatings so applied.

Evaluation of hot spray application is an aim of tests on panels exposed in 1955. The method is being tried with phenolics, alkyds and vinyls as well as with red lead and aluminum vinyls sprayed by the conventional low pressure method.

Hot Spray Has Promise

Two years' tests indicate the hot spray method has promise. Samples coated by roller are equally as good as brushed or sprayed samples with an advantage around rivet heads. Hot and cold applied vinyls have a first-class rating now.

In about five years better evaluation of the application methods can be made.

The exhibition scheduled to be held at New Orleans October 21-23 during the South Central Region's Conference at the Roosevelt Hotel will be the third held by the region.

Service Life and Relative Cost Data on Reinforced Epoxy Pipe*

Abstract

Data are presented on experience with reinforced epoxy pipe transporting numerous acids, alkalies and bases at various concentrations, pressures and temperatures. Tabulated are relative service life and relative cost versus service life against materials for which reinforced epoxy pipe has been substituted. Comparisons are made with aluminum, brass, glass, rubber, steel, stainless steel, several plastics other than epoxy and asbestos cement. A list of applications in which the material is being used is given and a short schedule of known failures, together with reasons for failure and remedial measures are included.

6.6.8

RECORDS show that roughly 80 percent of 1951-53 glass-mat reinforced polyester pipe is still in use today where the replaced material failed in 3 to 14 months. Principal installations were in oil fields for salt water disposal, sour crude oil gathering and some few chemical disposal applications. Because there were failures with this material and there was a serious limitation as to types of applications, 1953, 1954 and part of 1955 were devoted to research and development. This and new ideas concurrent with the availability of better materials resulted in epoxy pipe reinforced with braided glass sleeving.

Test installations of epoxy pipe began in 1954-1955. Some of these short sections are still in test and all served to evaluate pipe physicals before and after exposure. In July, 1955 the first complete installation of 3460 feet of oil well production pipe was made in a salt water disposal well. The user reports it paid out in 1½ years compared to the material replaced and is in service almost three years today. It is certain the tubing looks and will test like new today, with 95 to 98 percent of its original characteristics. It has lasted almost three times as long as the cement lined steel formerly used.

Acid has been used many times in the tubing to keep the formation open. It has not been necessary to pull and clean the well at all. Casing in the well has been preserved by kerosene in the annulus.

Table 1 lists several outstanding corrodents in a wide range of installations whose service history is known. Temperature ranges and pressure given represent the minimum and maximum of all. Maximum operating conditions are given also for each category. Examples cited do not necessarily represent the longest service or maximum temperature and pressure.

Out of 381 typical corrodents, rein-

TABLE 1—General Experience Data on Reinforced Epoxy Piping

Material Transported (Conc. %)	RANGES		MAXIMUM EXPOSURE			
	Deg. F.	psi	Service Months[1]	Conc. Percent	Deg. F	psi
Acids:						
Sulfuric, 10–50	100–290	0–250	18	50	240	75
Sulfuric, 60	260	30–300	6	60	190	300
Nitric, 5	180	110	24	..	180	110
Hydrochloric, 37	60–260	0–500	18	..	190	200
Hydrochloric, 18	120–300	0–375	26	..	180	300
Adipic acid solution[2]	270	175	8	..	270	175
Fatty Acid, 10–30	100–250	50–190	7	30	175	75
Phosphoric, 40–79	200–300	50–200	24	76	260	75
Hydrofluoric, 10–30	100–300	0–85	18	30	175	75
Phenol	75–260	0–200	12	..	200	200
Air	100–160	50–350	24	..	160	175
Alkalies:						
Ammonium hydroxide, 20	80–180	50–120	8	20	180	75
Sodium hydroxide, 20	100–250	30–150	6	50	230	40
Brine	40–275	0–1350	30	..	....	..
Saturated	Ambient	1300	30	..	....	..
Oil field[3]	Ambient	1100	25	..	....	..
Chlorine, wet	60	25	20	..	60	25
Chlorine, dry	90–120	35–75	30	..	120	70
Salts: (Solutions)						
Aluminum sulfate	100–220	150–275	14	..	220	200
Ammonium sulfate	75–280	30–300	13	..	200	150
Ammonium nitrate	50–250	0–200	17	..	190	200
Calcium chloride	150–325	0–175	13	..	325	175
Culric chloride	50–200	35–90	15	..	150	75
Ferric chloride	70–190	75–300	11	..	185	250
Stannic chloride	160	300	20	..	160	300
Sodium bicarbonate	100–200	50–500	26	..	180	300
Solvents:						
Alcohols, methyl	–40–120	50–175	15	..	–40	150
Benzene	80–120	150–500	30	..	100	325
Carbon tetrachloride	80–150	175–300	19	..	80	300
Ethyl acetate	80–120	0–115	9	..	110	60
Xylene	60–200	15–700	11	..	130	275
Trichloroethylene	50–170	20–75	15	..	160	25
Industrial Fluids:						
Black liquor	200	0–175	7	..	200	50
Bleach, 10–40	100–200	10–50	14	17	130	50
Pickling acid	190–260	50–130	10	..	215	20
Sewage	20–120	0–20	30	..	120	20
Organics:						
Too numerous to mention	30–320	0–1000	..	..	...	..

[1] Up to December, 1957.
[2] 7–10% adipic, 20–45% sulfuric, plus organics.
[3] With 200 ppm H_2S.

TABLE 2—Cost 3½-inch OD Reinforced Epoxy Pipe vs Other Materials
(All Epoxy Pipe Still in Service)

MATERIAL	Cost per 100 Feet 3-Inch Nominal			Cause of Failure
	Initial	Comparative	Life[1]	
Epoxy Pipe (200 psi)	$ 210.00	$ 210	100	....
Epoxy Pipe (300 psi)	240.00	240	100	....
Epoxy Pipe (500 psi)	300.00	300	100	....
Aluminum	82.95	319	26	Corrosion
Brass, (Red)	333.00	449	74	Corrosion
Glass	1,400.00	4,230	33.6	Breakage
Low-Pressure Filled Phenolic	492.00	732	67.1	Corrosion
Rubber Hose	658.00	3,135	21.0	Corrosion, Excessive Pressure
Steel:				
Schedule 40	75.15	826	09.1	Corrosion
Schedule 40 Cement Lined	91.93	598	15.3	Corrosion
Schedule 40 Galvanized	108.16	974	11.1	Corrosion
Schedule 40 Plastic Coated[2]	99.28	310	32.0	Corrosion
Stainless 304-40	772.00	2,480	31.1	Corrosion
Stainless 316-40	1,121.00	3,280	34.2	Corrosion
Butyrate (Slip Type)	69.15	2,165	03.2	Excessive pressure, Surge pressures, Structurally weak
ABS Plastics:				
Acrylonitrile Resin-Rubber Blends– (Slip Type)	70.04	4,220	01.7	Excessive pressure, Excessive heat
Polyvinylchloride:				
Schedule 40	168.75	1,112	15.2	Excessive pressure, Surge pressures, Structurally weak
Schedule 80	217.62	1,259	17.2	Excessive heat, Structurally weak
Asbestos:				
Cement C-100	81.00	342	23.7	Corrosion
C-150	87.00	450	19.3	Corrosion

[1] Using epoxy pipe life up to date of report as a base of 100, relative service life of materials for which it was substituted are given as percentages of the service life of epoxy pipe. Epoxy pipe life extends from installation date indefinitely because it all is still in use, therefore life percentage of competing materials is declining and their relative cost increasing.
[2] Modified phenolic epoxy coating, heat cured, internal only.

Service Life—

(Continued From Page 114)

forced epoxy pipe has a sound service
life in 320 at 80 F in 284 at 180 F and
in 214 at temperatures through 260 F.

Table 2 was compiled by taking spe-
cific cases—the outstanding case for a
particular piping material which rein-
forced epoxy pipe replaced—and then
computing the relative cost, based on
first cost, factored by comparative serv-
ice life. Since the reinforced pipe is still
in service these factors will change in
favor of reinforced epoxy pipe.

Table 3 gives useful data in the kinds
of applications that have been made
with reinforced epoxy pipe. Each in-
stallation has an outstanding condition,
either structural or environmental, or
both.

Failures due to product weakness or
attacks by corrodents have affected less
than 0.01 percent of all epoxy pipe in-
stalled. These are reported in Table 4.
Corrective action was taken and sub-
stantial improvements realized. Items to
match the new installation needs, such
as valves, packers, centralizers, etc. are
being developed in conjunction with
manufacturers who know their require-
ments.

So far no installation of factory made
reinforced epoxy pipe has been retired
from service. Considerable footage has
been placed in service in the last six
months, partly in new applications
where experience is not yet rated. As
the economics are more generally un-
derstood, and as epoxy pipe comes
closer to proving an 8 and 10-year life,
replacement of even 5-year life expect-
ancy material will be made at substan-
tial savings.

During 1957 over 140 discussions of
technical material in CORROSION
were published.

TABLE 3—Commercial Applications of Reinforced Epoxy Pipe

OIL & GAS INDUSTRY

1. Salt water disposal wells.
   a "Balanced Column"—Open end.
   b "Packer Method"—Retrievable or non-re
      trievable.
2. Combination injection-disposal wells.
3. Pumping Wells—530' to 2000', with anchor.
4. Mud anchors—bottom joints on steel tubing, be-
   low pump.
5. Gas aeration wells—for water supply wells.
6. Electrical pump supply wells—to supply injection
   water for water floods.
7. Gathering lines of all descriptions, headers, etc.
8. Surface lines where paraffinic action is severe to
   steel.
9. Tank battery hook-ups, complete pre-fabricated
   systems.
10. Water "knock-out" towers, heat exchangers,
    heater-treaters.
11. Gas transmission lines.
12. Electrolytic insulators.
13. "Shot-Hole" casing for exploration crews.
14. Antennae for sound and recording trucks.
15. Acid lines for workover operations.
16. Tank floats for control valves.
17. Liquid petroleum gas—LPG.
18. Road crossing conduit.
19. Oil well full-diameter core storage or shipping
    case.
20. Injection lines on both input and output sides of
    pump.

CHEMICAL INDUSTRY

1. Chemical disposal wells.
2. In-plant piping transporting numerous fluids.
3. Slurry lines to resist mechanical abrasion.
4. Overhead lines, where continuous support was
   necessary with other materials.
5. Plant lines, where insulation was necessary to
   prevent condensation.
6. Plant line, where external corrosion was a prob-
   lem.
7. Agitators for dump pits.
8. Sparger tubes for steam-heating fluid tanks.
9. Plant lines where plugging or steaming was nec-
   essary to remove buildup.
10. Sulphur recovery tubing.
11. Tubing for salt mining.

MISCELLANEOUS INSTALLATIONS

1. Electro-Stabilizers.
2. Insulators for transformer handles.
3. Electrical fuse bodies.
4. Map cases.
5. Vacuum chambers.
6. Pickling acid lines in steel plants.

TABLE 4—Some Epoxy Pipe Failures, Causes and Remedies[1]

| CONDITIONS | | | | |
Pressure (psig.)	Deg. F	Failure	Cause	Remedy
890	120	Beam failure in line protruding from 400' steel conduit.	Line "snaked" in conduit sufficient to cause beam failure at upstream end of conduit in one joint during 800 lb. test. This line was pressure loaded without backfilling and operated for 12 hours before uncoiling. Proper backfill on joint body, leaving collars clear, would have prevented.	After correction no further trouble.
75	220	Pipe "wept" after 30 day operation.	Badly crazed interior caused by "force Fitting" the installation using a brick as a hammer.	Better quality control of fittings has assured proper clearance. After correction no further trouble.
590	110	Burst type failure of one joint after six weeks' operation. Four joints damaged in shipment, all from same package.	Exterior surface damage caused during LTL shipment and improper inspection at installation.	New method of packaging and shipping instituted.
75	220	Flange was forced over pipe body in compression.	Line installed between lead lines and as temperature increased the expansion of lead caused shear joint failure at the flange.	Increased shear resistance of flange by changing configuration within the body. Developed more efficient high temperature cement which corrected the problem.
800	Ambient	Weep failure after six months' operation.	Factory flaw overlooked in inspection. Glass braid exposure due to damage to the braid in handling. Failure occurred where braid was displaced.	Joint replaced.

(1) These failures represent less than 0.01 percent of reinforced epoxy pipe installed.

Diminishing Cost Ratio
Favors Baked Pipe Coatings*

A principal reason for the increasing use of baked coatings on pipe is the rapidly diminishing cost of the coating versus cost of the pipe. In 1945 cost of coating almost equalled cost of pipe, but at present, as seen in the table below, this ratio of coating cost to pipe is rapidly going down.

TABLE 1—Cost of Baked Coatings vs Pipe

Size Inches	DESCRIPTION	Pipe/Ft.	Coating/Ft.	Coating % vs. Pipe	Spec. Jt. %
2⅜	J-55, 4.70#, 8 Rd.	$0.6683	$0.36	54	33
2⅜	N-80, 4.70#, 8 Rd.	0.8082	.36	45	30
2⅜	P-105, 4.70#, Int. Jt.	2.04	.36	18	
2⅞	J-55, 6.50#, 8 Rd.	0.8847	.46	53	38
2⅞	N-80, 6.50#, 8 Rd.	1.07	.46	43	31
2⅞	P-105, 6.50#, Int. Jt.	2.53	.46	19	
2⅞	P-105, 7.90#, Int. Jt.	2.97	.46	15	
2⅞	P-105, 11.65#, Int. Jt.	4.13	.46	11	

TECHNICAL REPORTS

on

Corrosion in Oil and Gas Well Equipment

T-1A   Survey of Corrosion Control in California Pumping Wells. A Report of T-1A on Corrosion in Oil and Gas Well Equipment, Los Angeles Area. Pub. 54-7. Per Copy, $.50.

T-1C   Current Status of Corrosion Mitigation Knowledge on Sweet Oil Wells. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion. Per Copy, $.50.

T-1C   Field Practices for Controling Water Dependent Sweet Oil Well Corrosion. A Report of Technical Unit Committee T-1C on Sweet Oil Well Corrosion, Compiled by Task Group T-1C-1 on Field Practices. Pub. No. 56-3, Per Copy $1.00.

TP-1D   Sour Oil Well Corrosion. *Corrosion* August, 1952, issue. NACE members, $.50; Non-members $1 Per Copy.

TP-1G   Field Experience With Cracking of High Strength Steel in Sour Gas and Oil Wells. (Included in Symposium on Sulfide Stress Corrosion.) (Pub. 52-3) $1 Per Copy, 5 or more copies to one address, $.50 Per Copy.

T-1G   Sulfide Corrosion Cracking of Oil Production Equipment. A Report of Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking. Pub. 54-5. $.50 Per Copy.

T-1G   Hydrogen Absorption, Embrittlement and Fracture of Steel. A Report on Sponsored Research on Hydrogen Sulfide Stress Corrosion Cracking Carried on at Yale University, Supervised by NACE Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking by W. D. Robertson and Arnold E. Schuetz. Pub. 57-17. Per copy $2.

T-1J   Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Per Copy $1.00.

T-1J   Reports to Technical Unit Committee T-1J on Oilfield Structural Plastics. Part 1, Long-Term Creep of Pipe Extruded from Tenite Butyrate Plastics. Part 2, Structural Behavior of Unplasticized Geon Polyvinyl Chloride. Publication 55-7. Per Copy $.50.

T-1J   Summary of Data on Use of Structural Plastic Products in Oil Production. A Status Report of NACE Technical Unit Committee T-1J on Oilfield Structural Plastics. Per Copy $.50.

T-1J   Service Reports Given on Oil Field Plastic Pipe. Activities Report of T-1J on Oilfield Structural Plastics. Per Copy $.50.

T-1J   Oilfield Structural Plastics Test Data are given. Activities Report of T-1J on Oilfield Structural Plastics. Per Copy $.50.

T-1J   Reports to Technical Unit Committee T-1J on Oil Field Structural Plastics. Part 1—The Long Term Strengths of Reinforced Plastics Determined by Creep Strengths. Part 2—Microscopic Examination as a Test Method for Reinforced Plastic Pipe. Per Copy $.50.

T-1J   Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Part 1—Laboratory Testing of Glass-Plastic Laminates. Part 2—Service Experience of Glass Reinforced Plastic Tanks. Part 3—High Pressure Field Tests of Glass-Reinforced Plastic Pipe. Per Copy $.50.

T-1J   Service Experience of Glass Reinforced Plastic Tanks—Status Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Pub. 57-18. Per Copy $.50.

T-1J   Experience with Oil Field Extruded Plastic Pipe in 1955—A Report of NACE Technical Unit Committee T-1J on Oil Field Structural Plastics. Pub. 57-19. Per Copy $.50.

T-1K   Proposed Standardized Laboratory Procedure for Screening Corrosion Inhibitors for Oil and Gas Wells. A Report of T-1K on Inhibitors for Oil and Gas Wells. Publication 55-2. Per Copy $.50.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg.   Houston 2, Texas

CORROSION ABSTRACTS

INDEX TO CORROSION ABSTRACTS

3. CHARACTERISTIC CORROSION PHENOMENA

3.7 Metallurgical Effects

3.7.3, 7.2, 6.2.5, 3.7.4

The Plastic Ductility of Austenitic Piping Containing Welded Joints at 1200 F. R. W. EMERSON AND R. W. JACKSON. Paper before Am. Welding Soc., Nat'l. Fall Mtg., Cleveland, October 8-12, 1956. *Welding J.*, 36, No. 2, 89s-104s (1957) Feb.

Objectives of investigation were to determine: if low-ductility failure could be induced in Type 347 heavy-wall welded tubular joints under test conditions similar to high temperature service; effect of base metal grain size on fracture ductility as measured by specimen elongation; possibility of metallurgical treatment which would improve hot plastic ductility across welded joint so that it would be more receptive toward acceptance of additional plastic strain; and comparison of Types 316 and 347 under similar conditions. AISI Type 316 and 347 2½-inch diameter bar stock were heat treated to produce variation in grain size, from which heavy-wall tubular specimens were machined. Specimens were U-beveled, welded using 2 different procedures and welded joints tested at 1440-1200 F. Tests were performed by inducing thermal strain in test section by internally heating specimen to 1440 F. Ends were rigidly fixed, and temperature of center section lowered to 1200 F, thus inducing mechanical strain. Specimens were reheated to 1400 F, load released and cooled to room temperature for elongation measurements. Centerline fracture, weld heat affected zone failures, stress-concentration failures and fusion-line failures were observed and discussed. Tables, graphs, photomicrographs.—INCO.   13909

3.8 Miscellaneous Principles

3.8.4, 6.3.15

Optical Properties and Oxidation of Evaporated Titanium Films. GEORGE HASS AND ALAN P. BRADFORD. Engineer Res. and Dev. Labs., Ft. Belvoir, Virginia. *J. Opt. Soc. Amer.*, 47, 125-129 (1957) Feb.

Measurements were made of the optical constants and of the reflectance and transmittance of titanium films evaporated onto fused quartz and glass. In order to prepare pure titanium films with normal density, all depositions were carried out at a pressure $p < 5 \times 10^{-6}$ mm. mercury and with a deposition rate $D > 40$ Å/sec. The optical constants were determined by Drude's polarimetric method from opaque films at the wavelengths 0.436μ, 0.546μ, 0.578μ, and 0.650μ. The reflectance values computed from n and k agreed well with the directly measured ones. The reflectance of titanium was measured from 900 Å to 10μ. 100 Å to 300 Å thick films of titanium were found to have quite uniform transmittance throughout the visible spectrum and can, therefore, be used as neutral density filters. Three optical principles were used to measure the oxidation of titanium in air. At room temperature the rate of oxidation of titanium was found to be almost equal to that of aluminum (about 35 Å of oxide are formed in one month). With increasing temperature, however, the oxidation of titanium increases much more rapidly than that of aluminum. (auth)—NSA.   13741

3.8.4, 6.3.6, 3.2.3

On the Diffusion of Atoms of Copper and Oxygen During the Formation

of a Copper Oxide Layer. (In Russian.) A. I. ANDRIEVSKY AND M. T. MISCHENKO. *J. Tech. Physics, USSR* (Zhur. Tekh. Fiz.), **26**, No. 2, 430-435 (1956).

Micrographs showing the texture of cuprous oxide layers formed at various temperatures give support to theories of oxidation which require diffusion of both copper and oxygen across the interface. Andrievsky and Mischenko investigated the relative magnitudes of the two diffusion coefficients: at temperatures less than 1020 C diffusion of oxygen is faster than the diffusion of copper in the opposite direction. As the temperature of oxidation is raised to more than 1020 C the diffusion of copper begins to predominate and the higher the temperature, the larger is the relative importance of the diffusion of copper—MA.   13497

4. CORROSIVE ENVIROMENTS

4.3 Chemical, Inorganic

4.3.2
Give Us Something on Acid Handling. L. RESEN. *Oil Gas J.*, **55**, No. 14, 93-95 (1957) April 8.

Discussion of problems of corrosion and safety factors in acid handling. Problem of acid pump corrosion was solved by redesign of acid-proportioning pump and difficulties in operation of an acid system were diminished by use of refrigeration gas to pressure blowdown tanks. In handling sulfuric acid, 316 stainless used in pumps, valves and bellows eliminated failures. Photos, diagrams.—INCO.   14152

4.3.2, 4.3.5, 6.3.10
Behavior of Nickel and Its Alloys in the Presence of Halogens. L. ARBELLOT. Paper before 1st Congress European de la Corrosion, Paris, Nov. 1956. *Corrosion et Anticorrosion*, **5**, 112-118 (1957) April.

Data in tabular form on mechanical properties of nickel, Monel, K, S and H Monel, 18% nickel silver, 18/8 and Hastelloy A, B, C and D. Behavior of above materials and 18/8/3 molybdenum, in chlorine, dry, slightly humid and gaseous hydrochloric acid, aqueous solutions of chlorine, hydrochloric solutions and hypochlorites is discussed. Notes and data are given on high-temperature attack of fluorine and hydrofluoric acid on nickel, Monel, Inconel, copper, aluminum, Armco iron, steel, 18/8/3 molybdenum and 18/8 stabilized with niobium. Corrosion rates for Monel in mixture of hydrofluoric acid and water vapor and corrosion of nickel, Hastelloy B and C by iodine, by bromine and a 10% aqueous solution of bromine are included. —INCO.   14209

4.3.2, 5.4.8
Problems of Corrosion Protection and Materials in Modern Acid Engineering. (In German.) G. SCHUECKING. *Werkstoffe u. Korrosion*, **7**, No. 11, 615-626 (1956) November.

Methods for protecting concrete and metals and characteristics and application of protective coatings are discussed. Recent research on acid resistant coatings, current types of cement and putty and examples of author's development and research work in acid engineering are reviewed. 31 references.—BL. 13852

4.3.2, 5.8.2, 6.2.5
Corrosion of a Stainless Steel Containing 13% Chromium and 8% Nickel in Acids and Their Mixtures. W. MACHU

AND M. G. FOUAD. *Arch. Eisenhuttenw*, **28**, 157-165 (1957) March.

Study of corrosion of a 13/8 chromium-nickel steel in hydrochloric, sulphuric and phosphoric acids and their mixtures. Effect of organic and inorganic corrosion inhibitors is discussed. —INCO.   14142

4.3.2, 6.2.5, 5.8.2
Inhibiting Effect of Hydrofluoric Acid in Fuming Nitric Acid on Corrosion of Austenitic Chromium-Nickel Steels. CLARENCE E. LEVOE, DAVID M. MASON AND JOHN B. RITTENHOUSE. *Corrosion*, **13**, No. 5, 321t-328t (1957) May.

The rate of corrosion of welded and unwelded chromium-nickel steels, Uniloy 19-9DL and 19-9DX and welded alloy 321 by fuming nitric acid in the liquid and the gas phase was measured with and without hydrofluoric acid added as a corrosion inhibitor. Corrosion by this system is of interest because of its widespread use as a rocket propellant. The effect of heat treatment on the corrosion process was measured by performing tests on one set of samples annealed at 1800 F and air-cooled and on another series of samples that had been work-hardened and stress-relieved at 1200 F. In general, samples in the latter condition had the least corrosion resistance. It was found that 0.6 weight percent hydrofluoric acid in fuming nitric acid inhibits both liquid- and gas-phase corrosion in all cases in which uncorroded metal was exposed to the acid. Most of the measurements were conducted at 130 and 160 F although a few measurements were made at 100 F to determine the effect of temperature on the corrosion process. Inhibition was also effective with temperature fluctuating between 70 and 160 F. When the metal had previously undergone intergranular corrosion, however, the presence of hydrofluoric acid in fuming nitric acid aggravated the corrosive attack.   13933

4.3.2, 6.6.6
On the Action of Acid Solvents on Certain Hard Silicides and High-Melting Metals. (In German.) M. K. DISEN AND G. F. HUTTIG. *Planseeber. Pulvermet.*, **4**, No. 1, 10-14 (1956) April.

Tabulated data on the solubility of $MoSi_2$, WSi_2, VSi_2, $NbSi_2$, $TaSi_2$ and $ZrSi_2$, as well as metallic titanium, zirconium, chromium, molybdenum and tungsten in various acid solvents.—MR.   13882

4.3.5
Material Compatibility with Gaseous Fluorine. H. G. PRICE, JR. AND H. W. DOUGLASS. Lewis Flight Propulsion Lab. U. S. National Advisory Comm. for Aeronautics, Research Memo E56K21, January 23, 1957, 5 pp.

Static tests were made on compatibility of gaseous fluorine with various liquids, waxes, plastics and other solids (including flux on silver-soldered copper-to-brass joint and on stainless steel joint, slag on stainless steel weld joint) at pressures of 0 and 1500 psig and at-mospheric temperature. Several materials were found compatible at atmospheric pressure. Only Teflon and ruby (aluminum oxide) were compatible under static conditions. Table.—INCO.   13828

4.6 Water and Steam

4.6.2
Simplify Boiler Water Treatment. M. BROOKE. Phillips Petroleum Co. *Petroleum*

Refiner, **35**, No. 11, 193-196 (1956) Nov.

Rational method for boiler saline treatment to prevent common problems associated with steam generation. Covered in the review are: prevention of corrosion of boiler surfaces by pH control, of steam and condensate lines by oxygen removal, carbon dioxide removal and neutralization and inhibitors for intercrystalline cracking; prevention of scale by external feed water treatment (lime-soda, phosphate, ion exchange) and by internal treatment (soda, ash, sodium hydroxide, phosphates, organics); and prevention of carry-over due to foaming and priming, mechanical carry-over and carry-over in steam solution. Several specific examples are cited. Tables, 29 references.—INCO.   13531

4.6.2
Symposium on Steam Quality. ASTM Special Technical Publication No. 192, December, 1956, 49 pp. American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

Four papers presented at a symposium June 21, 1956, on steam quality are presented: Measurement and Purification of Steam to 0.01 ppm Total Dissolved Solids, W. B. Gurney; Steam Purity Determination by Trace Techniques, E. E. Coulter and T. M. Campbell; Comments on Corrections to Steam Conductivity Measurements, R. O. Parker and R. J. Ziobro; Construction and Operation of Larson-Lane Steam Purity and Condensate Analyzers, A. B. Sisson, F. G. Straub and R. W. Lane.   13482

4.6.5, 3.8.4
The Corrosion of Iron in High-Temperature Water. Part II. Kirkendall Experiments. D. L. DOUGLAS and F. C. ZYZES. *Corrosion*, **13**, No. 7, 433t-436t (1957) July.

Kirkendall-type experiments were carried out in order to identify the ion species diffusing through the magnetite film formed on corrosion of iron in high temperature water. Iron disks were painted with a slurry of $Ni^{63}O$, and the surface activity was measured. After corrosion the activity decreased. This decrease is shown to be most readily explained by a covering of $Ni^{63}O$ by magnetite formed as iron ions diffuse outward from the metal-oxide interface to the oxide-water interface.   13871

4.6.5, 5.4.8, 6.4.2, 5.3.2
The Storage of High Purity Water. RICHARD R. DLESK. *Corrosion*, **13**, No. 9, 585t-588t (1957) Sept.

A need is developing in industry for water of higher and higher purity. As the purity of the water increases, the storing of it becomes an increasingly difficult problem. In order to mitigate this problem, investigations and appraisals of new protective measures for existing steel tanks were made, and some were applied to actual installations. Protective coatings discussed include red lead paint, metallic zinc paint, synthetic rubber, nickel-phosphorous-alloy coating, heavy electroplated nickel and metallized aluminum coatings.

Aluminum, as a construction material for storage facilities, was evaluated in laboratory and field tests. These tests resulted in the construction of four 44,000-gallon aluminum storage tanks. Data were reported to show the electrical resistance of a film developed on 3003 aluminum alloy in tap water, distilled water and demineralized water.   14189
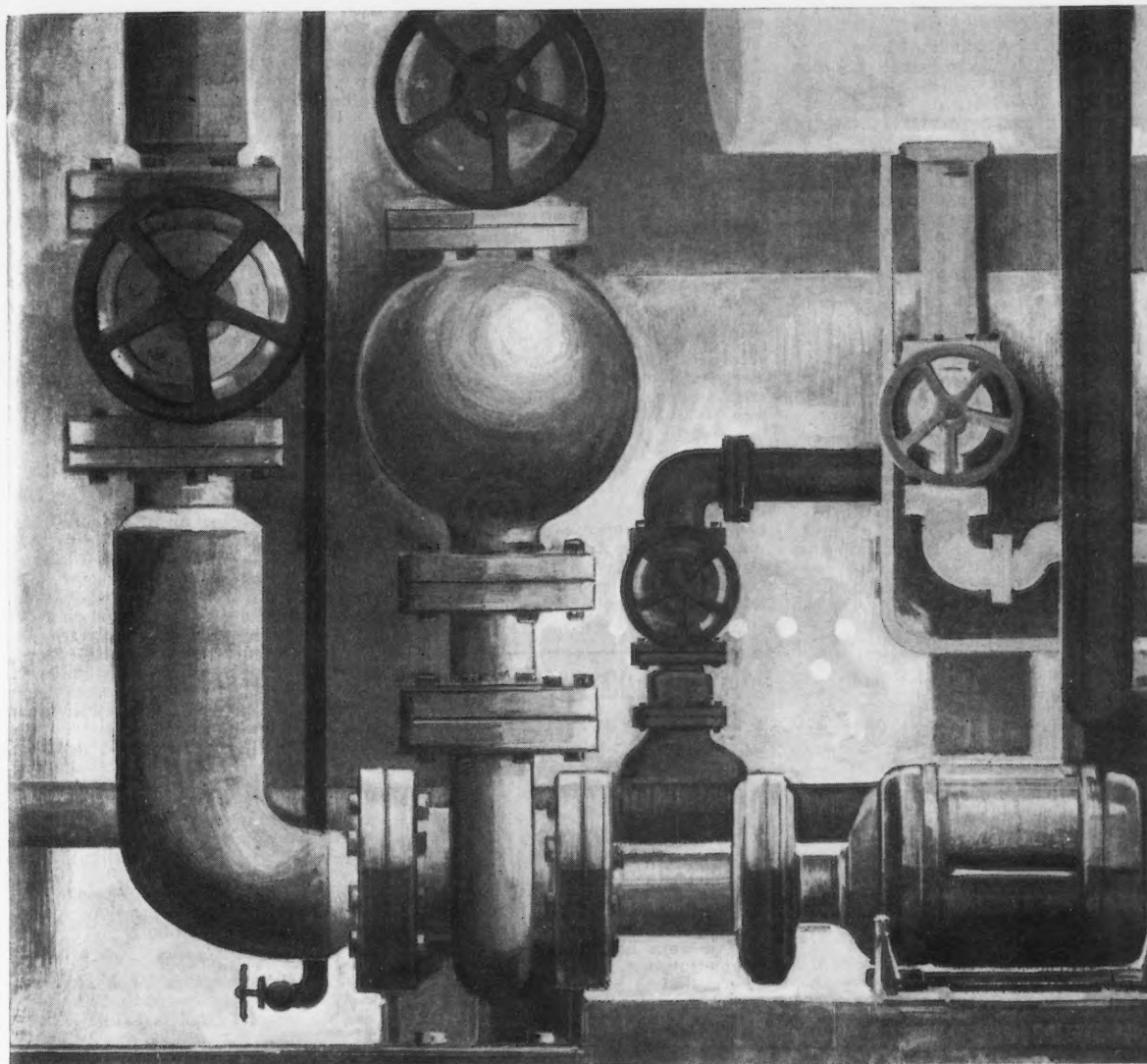
This superior inhibitor saves you money on replacement of corroded pipes and pumps, prevents schedule-shattering downtime for frequent maintenance.

Seal closed or re-circulating systems against costly corrosion with durable protective film of Columbia-Southern Sodium Chromate

One of the most effective, yet low-cost corrosion inhibitors for metallic systems found yet! Columbia-Southern's Sodium Chromate is solving expensive corrosion problems today in air conditioning equipment, refrigerating systems, diesels, cooling towers, heat exchangers, boilers, marine engines, hot water heating systems, automobiles, pumping and compressor stations.

The durable protective film formed by Columbia-Southern Sodium Chro-

mate gives vulnerable inner pipe surfaces a true chemical barrier against corrosion. Straightaways, joints and turns get equal protection. And this film is self-renewing as long as sufficient chromate is present in the solution. Active chromate ions immediately rush to seal any point of the film scratched or broken by abrasion.

Columbia-Southern's quality-controlled Sodium Chromate is packaged as an anhydrous powder in 100

lb. bags and 200 lb. fiber drums. Write to our Pittsburgh address or to any of our fourteen district offices for full use information.

COLUMBIA-SOUTHERN CHEMICAL CORPORATION
SUBSIDIARY OF PITTSBURGH PLATE GLASS COMPANY
ONE GATEWAY CENTER · PITTSBURGH 22 · PENNSYLVANIA

DISTRICT OFFICES: Cincinnati • Charlotte Chicago • Cleveland • Boston • New York • St. Louis • Minneapolis • New Orleans • Philadelphia • Houston Pittsburgh • Dallas • San Francisco
IN CANADA: Standard Chemical Limited and its Commercial Chemicals Division

4.6.5, 6.4.2

Corrosion of Aluminum-Nickel Type Alloys in High Temperature Aqueous Service. F. H. KRENZ. *Corrosion*, 13, No. 9, 575t-581t (1957) Sept.

Aluminum can be made resistant to high temperature water by small alloying additions of nickel, iron and copper. In the presence of adequate concentrations of the cathodic second phase formed by these additions, the high temperature attack changes from grain boundary penetration and blistering to a more desirable uniform overall attack. The latter causes two films to be formed on the corroding surface, Film A growing outward from the original surface and Film B growing inward into the metal. Film A reaches a limiting thickness after 2-3 weeks at 300 C, but Film B continues to grow linearly with time. At this stage the corrosion rate is acceptably low (~ 1 x 10^{-3} inches/yr.) but the corrosion film is 10-20r thick, relatively brittle and subject to severe mechanical damage in water flowing at high linear velocities. Reactor radiation has an insignificant effect upon corrosion. Heat fluxes of the order of 100 watts/cm² also appear to have little effect, though in this instance the effect may have been obscured by mechanical damage.

Extensive test data are reported on the corrosion resistance in high temperature water of three specially selected aluminum alloys.   14197

4.7 Molten Metals and Fused Compounds

4.7

The Effect of Fused Lithium. Sodium and Potassium Nitrates on Nickel, Copper, Duralium, and Some Steels. E. I. GUROVICH. J. Applied Chem., USSR *(Zhur. Priklad. Khim.)*, 29, No. 9, 1358-1365 (1956).

An experimental determination of the relationship between corrosion of metals in above salts and time and temperature, and of the mechanism of the salts' action. 2 tables, 6 figures, 26 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.   12814

4.7

The Attack of Unstressed Metals by Liquid Mercury. J. F. STRACHAN AND N. L. HARRIS. *J. Inst. Metals*, 85, Pt. 1, 17-24 (1956) Sept.

Saturated solubilities and weight losses at room temperature of most of the metallic elements in static liquid mercury were determined, as well as attack on bright-annealed and unstressed commercial nickel, Inconel, Nimonic 75. 50-50 nickel-iron, 25-20, 18-8, mild steel, iron, molybdenum and tungsten in static liquid mercury at 300 and 500 C for up to 2000 hours. No significant changes took place in mechanical properties of iron, molybdenum, some steels and nickel alloys after 2000 hours in mercury at 500 C. Nickel suffered a decrease in maximum stress, yield stress and elongation of about 50%. Periodic table gives percent solubility of metallic elements, including nickel, cobalt and platinum group metals, in liquid mercury at room temperature. Graph, tables, 11 references.—INCO.   12965

4.7, 3.6.5

Electrode Potentials in Fused Sys-

tems. Part III. The Platinum Electrode in Some Halide Melts. K. H. STERN. *J. Phys. Chem.*, 60, No. 10, 1443-1445 (1956) Oct.

Galvanic cells silver/silver chloride, potassium chloride; potassium chloride/platinum, silver/silver bromide; potassium bromide/platinum, and copper/cuprous chloride, potassium chloride; potassium chloride/platinum were studied at 800-900 degrees. The K^+ —K(g) equilibrium operates on the platinum electrode at pressures near 10^{-15} atmosphere. Tables.—INCO.   12952

4.7, 5.8.2

Inhibition of Liquid-Metal Corrosion. J. W. TAYLOR. Gt. Brit. Atomic Energy Res. Establishment, Rept. M/TN35, Feb. 10, 1956, 7 pp. Photocopies available from Science Library, Science Museum, London, S.W.7.

Seven types of liquid metal corrosion are known, the most important being mass transfer and corrosion caused by impurities (usually oxide). Inhibitors are classified as either scavenging (capable of removing undesirable impurities) or diffusion barrier types (forming a surface film on the solid which prevents contact with the molten metal). Possible inhibitors for molten bismuth are considered in detail.—BNF.   12957

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1, 5.4.5

A study of Current Distribution in Cathodic Protection. E. E. NELSON. *Corrosion*, 13, No. 5, 315t-320t (1957) May.

An analysis is made of the effects of solution resistance and cathodic polarization on the current distribution in cathodic protection of metals. Two of Kasper's formulas relating to the effect of resistance are discussed. Hoar and Agar's formula relating resistance and polarization to current distribution, presented as a background, was modified and used as the basis of a partially quantitative treatment of the relative importance of resistance and polarization in influencing current distribution. It is shown that resistances can have a much greater effect in this respect than polarization.

An experimental method of obtaining the current density on various parts of a large cathode is described and data obtained by this method are presented. These show the distribution of current on a large cathode in sea water as affected by the magnitude of applied current and by shields around the anode. Solution resistances are calculated from the data and compared with Kasper's formulas. Using previously published data for the resistance of paint films, calculations are presented showing the effect of paint films on current distribution. The advantages of good paint coatings in cathodic protection and the difficulties of cathodically protecting unpainted structures are discussed.   13889

5.2.1, 5.4.10

The Application of Cable in Cathodic Protection. Pt. I. M. A. RIORDAN. Pt. II. R. G. FISHER. *Corrosion*, 13, No. 8, 519t-526t (1957) August.

The requirements of a suitable metallic conductor in a cathodic protection system are discussed. Particular attention is paid to economic factors and

power loss in the selection of suitable conductors and the most satisfactory cable sizes. Data are given to show the relative electrical resistivity of copper, aluminum, iron and lead.

The selection of cable insulation and protective coverings in cathodic protection systems is discussed in detail. Data are given to show physical and accelerated aging requirements of polyethylene insulation and polyvinyl chloride sheath compound. Data also included show the electrical stability of various types of insulation after immersion in tap water and after immersion in various chemicals. Other topics discussed include mechanical properties of insulation, insulation versus environment, installation techniques and splicing requirements.

It was found that a cable construction which makes use of a polyethylene insulation and a polyvinyl chloride sheathing compound has the best combination of properties for use in cathodic protection.   14015

5.2.1, 8.4.3, 7.2

Cathodic Protection of Oil Well Casings at Kettleman Hills, California. J. K. BALLOU and F. W. SCHREMP. *Corrosion*, 13, No. 8, 507t-514t (1957) August.

Results are reported of cathodic protection tests made on three oil well casings at Kettleman Hills, California. The tests showed that cathodic protection is a practical method of controlling external casing corrosion at least to depths of 8000 feet, provided sufficient current is used. Current densities on the order of 1.0 to 1.5 ma per sq ft are believed necessary to provide essentially complete protection to wells in the area. Both surface potential and casing potential profile measurements were made during the tests. Inexpensive surface measurements of casing potentials referred to a remote reference electrode can be used to indicate with reasonable accuracy the degree of protection obtained with cathodic protection.   14105

5.2.1, 8.9.3

Cathodic Protection for Modern Gas Service. K. A. CHEN. Milwaukee Gas & Light Co. *Gas Age*, 119, No. 7, 42, 44-45 (1957) April 5.

Description of new and tested developments in cathodic protection of cast iron, bare steel, coated steel and copper tubing used in gas distribution. Diagrams.—INCO.   14052

5.2.1, 8.9.5

Cathodic Protection of Ship Hulls. I. Potential Measurement on Ships in Gdansk & Gdynia Harbors; Tests of Cathodic protection on a Model of a 10,000 DWT Ship. (In Polish.) R. JUCHNIEWICZ. *Przemysl Chem.* 13, 26-30 (1957) Jan.

A steel model (working surface 3.5 sq. m.) was cathodically polarized by a current of 7.5 mv. to a protective potential determined against a silver-silver chloride electrode.—BTR.   14082

5.3 Metallic Coatings

5.3.4

Effects of Impurities and Purification of Electroplating Solutions. I. Nickel Solutions. 9. The Effect and Removal of Aluminum. D. T. EWING, A. J. SMITH AND W. O. Dow. Paper before Am. Electroplaters' Soc. 43rd Ann. Conv., Washington, D. C., June 17-21, 1956. *Tech. Proc. AES*, 1956, 44-46.

Preparation of deposits and evaluation

of effect of aluminum on appearance, adhesion, ductility, hardness, throwing power and salt spray corrosion resistance are discussed. Aluminum as hydroxide precipitate, or in solution has small effect on physical properties of nickel deposits. High or low current density electrolysis is completely ineffective in removing aluminum. High pH precipitation of aluminum hydroxide is complete at pH values above 5.0, and at pH 4.5 all but 10 mg/1 are removed.—INCO.   13543

5.3.4

Chromizing for Resistance to Corrosion and Wear. D. E. LEHANE AND R. L. WACHTELL. *Product Eng.*, **27**, No. 12, 180-183 (1956) Nov.

Distinguishes between the ductile and hard cases formed on low- and high-carbon steels respectively; typical applications for each type; chromizing special alloys, molybdenum, tungsten, nickel alloys, graphite and cermets.—BNF.   13650

5.3.4

Good Rinsing for Good Plating. J. B. KUSHNER. *Electroplating*, **9**, No. 2, 44-47 (1956) Feb.

The importance of good rinsing is stressed, seven main recommendations being made. They are: pure water obtained by de-ionization is essential, an adequate supply of water is needed, agitation is important, wetting agents can improve rinsing considerably, rinse water should not be too cold, enough time should be allowed for rinsing and the rinse tank should be kept as small as possible.—ZDA.   13640

5.3.4

Investigation of Chromium Plating Baths of the Combined Type. (In Russian.) N. T. DROBANTSEVA AND A. N. SYSOEV. *J. Applied Chem., USSR* (Zhur. Priklad. Khim.), **29**, No. 4, 589-595 (1956).

Addition of the sulphates of sodium, lithium, zirconium and cesium to a "standard" chromium-plating bath containing chromium trioxide 250 g./1. $+$ 1% sulfuric acid had little effect on the process, the current efficiency (η) remaining at 12-15%. Addition of tungsten or molybdenum to the bath led to the formation of alloy deposits of high corrosion-resistance, but to very low η. Sulphate-free fluoride baths were found to be unstable in operation over a wide range of current densities and temperatures (including low temperature and current density) and after passage of 18-20 amp.-hr./1. point excrescences and black streaks appeared on the surface of the deposits. It was only when SO_4^{2-} ions were also present (at least 0.5% of the chromium trioxide content) that η rose to 12-13%. Poor-quality deposits at low η were obtained from baths containing small amounts of hydrofluoboric acid, while baths containing additions of only fluosilicic acid also gave poor deposits with $\eta \geqslant 15\%$. However, a "combined" bath containing 250 g./1. $+$ 2% fluosilicic acid $+$ 0.5% sulfuric acid gave good-quality deposits at high η (up to 25% at least) over a wide range of temperatures and current densities; a bath containing sulfuric acid, fluosilicic acid and hydrofluoboric acid also operated at high η (up to 22%). These observations are contrary to the conclusions of Bil'finger ("Tverdoe Khromirovanie", 1947). The "combined" bath

was stable and had good throwing power; the mean rate of deposition of chromium from it was greater than that from the "standard" bath under all ordinary conditions of operation (temperature 45° C., cathodic current density 10, 25, 40 amp./dm.²), e.g. 30 μ/hr. as compared with 15.5 μ/hr. for the "standard" bath. Photomicrographs of the deposits show that those from the "combined" bath contain much finer and less extensive cracks than are present in "standard" deposits. X-ray measurements showed that in both types of deposit there was preferential orientation of the (111) plane $||$ the surface of the basis metal. The degree of orientation of the crystallites was more influenced by the current density and temperature of deposition than by the addition of anions to the bath. Deposits from the "combined" bath were found to be somewhat harder and less porous than those from the "standard" bath.—MA.   13602

5.4 Non-Metallic Coatings and Paints

5.4.5

Anticorrosive Paints. A. ALLAS. *Pitture e Vernici*, **12**, Nos. 2, 3, 111-116, 183-188 (1956).

The electrochemical theory of corrosion, metal oxidation, pretreatment for painting, phosphating, types of anticorrosive paint and the applications of aluminum-pigmented paints are reviewed.—RPI.   13950

5.4.5

Comparative Weathering Tests with Asser and Atlas Instruments on Some Commercial Synthetic Resin and Nitro White Enamels. (In German.) H. GERET. *Schweiz. Archiv angew. Wiss. u. Tech.*, **22**, No. 3, 97-101 (1956) March.   13970

5.4.5

Influence of the Type and Amount of Pigment on the Permeability of Paint Films. H. BERGER. *Deut. Farben-Z.*, **10**, Nos. 6, 7, 211-215, 243-251 (1956).

The porosity, true and apparent swelling and permeability of paint films with various media was measured in 0.01 N hydrochloric acid solution after the effects of acid concentration, film thickness and straining of the paints had been examined. For insoluble pigments such as zinc sulfide and lithopone, permeability decreased with the pigmentation in slightly porous, weakly swelling media and increased in porous, strongly swelling media. For zinc oxide, which was dissolved by the electrolyte, permeability decreased with pigmentation in non-porous, moderately or strongly swelling media and increased in porous, swelling media and, above a certain pigment concentration, in weakly swelling, slightly or very porous media. The influence of pigmentation on the swelling characteristics of various types of media is discussed. The zinc oxide was dissolved out if the medium was weakly swelling or porous, or strongly swelling and non-porous.—ZDA.   13965

5.4.5

Silicone Finishes. P. A. J. GATE. *Bull. Inst. Metal Finishing* (Trans. IMF, **6**, No. 3, 1827 (1956) Autumn.

An account of properties of silicone resins useful in surface coating.—BNF.   13968

5.4.5

Vinyl Coatings for Metal Products. R. A. CALSIBET. *Materials and Methods*, **45**, 130-134 (1957) Mar.

Properties, methods of application and uses of vinyl coatings of work primer, solution and dispersion types.—MR.   14058

5.4.5

Phenolic Coatings for Metal Products. R. B. YOUNG. *Materials and Methods*, **45**, No. 1, 106-109 (1957) Jan.

Discussion of four principal types of phenolic coatings, their resistance to chemicals, solvents, oil and water and their abrasion and mar resistance. Properties, uses and cost of coatings covered.—BL.   13862

5.4.5

How to Determine a 'Comparable Cost' for Paints. V. B. VOLKENING and J. T. WILSON, JR. *Corrosion*, **13**, No. 8, 505t-506t (1957) August.

A formula is given which can be used to calculate the percent solids by volume in paints when the percent solids by weight, weight of paint and density of volatile component are known. The value obtained then can be inserted into a second formula to determine the comparable cost for paints in dollars per mil square foot. A nomograph is included which can be used to determine both the percent solids by volume and the comparable cost for paints. A sample problem is worked out on the nomograph.   14106

5.4.5

Failure of Organic Coatings. S. KRISHNAMURTHY. *Paintindia*, **6**, No. 1, 119-122 (1956).

Various forms of breakdown (blistering, chalking, etc.), of paint films are discussed.—RPI.   14026

5.4.5

Thixotropic Coating on Metals. (In German.) SHIGETO YAMAGUCHI. *Kolloid Z.*, **149**, 125-126 (1956) Dec.

If a thixotropic sol-gel protective layer is subjected to long periods of inactivity, irreversible alterations cause deterioration. 2 references.—MR.   14036

5.5.1

Temporary Protective Coatings for Metals. V. Essential Requirements. E. STRONG. *Products Finishing*, **10**, 79-91 (1957) January.

Tabulated data on the composition of a wide range of temporary protective coatings and on their performances under accelerated test conditions.—BTR.   13860

5.9 Surface Treatment

5.9.4, 3.5.9

Corrosion Resistance of Phosphated Steel after Heating. J. DOSS. *Org. Finishing*, **17**, No. 8, 6-9 (1956).

Zinc and manganese phosphate coatings were heated under oil at 25° intervals in the range of 175-450 F. Accelerated corrosion tests on these coatings indicated that zinc phosphate coatings began to lose their corrosion resistance when heated, in the absence of air, between 300 and 325, manganese phosphate between 400 and 425 F. The heating of the phosphate coating in the absence of air is similar to the baking of paint on phosphated pieces. Therefore, the performance of zinc phosphate coatings under paint requiring baking is satisfactory, since the coating is not heated to a temperature which will decompose the coating and decrease the corrosion protection offered by it.—RPI.   13575

5.9.4, 6.2.2

Origin of Graphite in Cast Iron. J. E. HARRIS and V. KONDIC. *Foundry Trade J.*, **102**, Nos. 2107, 2108, 267-277, 311-314 (1957) Feb. 28, Mar. 7.

Previous work on origin of graphite in cast irons is considered and two mechanisms for flake-graphite phase formation are discussed. Direct mechanism assumes that graphite forms during solidification by process of nucleation and growth directly from liquid. Present work presents evidence to support indirect mechanism whereby graphite is obtained by decomposition of Fe_3C in solid state. Reheating tests, kinetic studies and quenching tests are described. Effects of alloy composition and molten-metal treatment and rate of cooling during and immediately following solidification were studied in relation to graphite formation by both processes. Results show that decomposition of Fe_3C into δ iron and graphite during and immediately after solidification is of far more frequent occurrence than hitherto considered. On this basis, theory for graphite formation through decomposition of Fe_3C in hypoeutectic cast irons is put forward. Cooling and decomposition curves, photomicrographs. —INCO.   13743

5.9.4

Effect of the Chromic Acid Rinse on Phosphate Coatings. J. DOSS, W. D. McHENRY and S. L. EISLER. *Organic Finishing*, **18**, No. 2, 4-6, 8 (1957).

Steel specimens were phospated in each of 5 phosphating baths containing P-32, a radioactive isotope of phosphorus, as a tracer. Activity measurements were made before and after immersion of the phosphated specimens in one of three chromic acid rinses. The percent loss of phosphate due to the stripping action of the chromic acid rinse was calculated from the counting rates obtained. Specimens were then subjected to salt spray and boiling tests and the efficiency of the rinses as regards corrosion inhibition was noted.—RPI.   14257

5.9.4

Mechanism of the Electrochemical Polishing of Metals. S. YA. GRILIKHES and N. P. FEDOT'EV. *J. Applied Chem USSR* (Zhur. Priklad. Khim.), **30**, No. 4, 528-533 (1957).

Experiment distinguishes between smoothing of the surface and increasing its reflecting power. 5 figures, 4 references.—ATS. Translation available: Associated Technical Services, P. O. Box 271, East Orange, New Jersey.   14306

5.9.4, 3.8.4

Anodic Oxidation of Aluminum, Chromium, Hafnium, Niobium, Tantalum, Titanium, Vanadium, and Zirconium at Very Low Current Densities. HERMAN A. JOHANSEN, GEORGE B. ADAMS, JR. and PIERRE VAN RYSSELBERGHE. *J. Electrochem. Soc.*, **104**, No. 6, 339-346 (1957) June.

Some aspects of the mode of formation of anodic oxidation films in the potential region below oxygen evolution were examined for a number of metals under as nearly constant experimental conditions as possible. The metals selected were aluminum, titanium, hafnium, vanadium, niobium, tantalum and chromium. Results for zirconium were reported in earlier publications. Electrolytic parameters and formation fields were evaluated from the unitary formation rates. Local currents were estimated using the method described previously.   14278

5.9.4, 5.3.2

Two-Step Process Retards White Rust. L. J. BROWN. Penna. Salt Mfg. Co. *Iron Age*, **178**, No. 19, 106-109 (1956) Nov. 8.

Corrosion resistance tests (pressure cooker, water film, condensation and "stack" tests) showed beneficial effect of various treatments for galvanized steel sheet: immersion in dilute aqueous solutions of fatty amine acetates, neutral oleates and stearates to form hydrophobic films. Further improvement resulted from subsequent treatment in dilute chromic solutions without impairing hydrophobic properties.—BNF.   13930

5.9.4, 5.3.2

Evaluation of Phosphate Coating Over Electrodeposited Zinc. A. L. ALEXANDER. Paper before American Society for Testing Materials, Symp. on Properties, Tests and Performance of Electrodeposited Metallic Coatings, Spr. Mtg., Buffalo, Feb. 29, 1956, and 2nd Pacific Area Nat'l. Mtg., Los Angeles, Sept. 19, 1956. ASTM Special Technical Publication No. 197, 1957, 97-104; disc., 105-106.

Two methods for determination of

phosphate coatings applied to zinc plate were examined—one employing vanadate-molybdate stripping solution and the other sodium hydroxide solution. Vanadate-molybdate method gives more consistent results while sodium hydroxide method is more simple and direct. Steel panels were coated with zinc plate from both alkaline and acid baths to minimum thickness of 0.2 mil. Plated panels received phosphate coatings of 4 different weights. Phosphated panels were varnished and evaluated with unvarnished and unphosphated panels. Tests include exposure to salt spray, humidity in laboratory, seaside atmosphere at Kure Beach and tropical atmosphere at Panama Canal Zone. Tables, photographs of specimens.—INCO.

14199

---

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.2, 3.2.3
Studies on Corrosion of Iron. (In German.) S. YAMAGUCHI AND Y. AOYAMA. *Werkstoffe u. Korrosion*, 7, No. 11, 626-628 (1956) Nov.

Ferromagnetic and paramagnetic iron oxides are discussed. Formation of gamma and alpha iron rust and how conditions of their formation are affected by magnetic behavior of iron oxides included. Results of magnetic test are confirmed by those of X-ray structure investigations.—BL. 13876

6.2.2, 3.7.2
Investigation on Acid-Resistant High-Silicon Iron. Rept. II. Effects of Alloying Elements on Mechanical Properties, Corrosion Resistance and Shrinkage. Pt. I. H. SAWAMURA, O. TAJIMA, K. AKAMATSU AND H. MURANAKA. *J. Iron Steel Inst. Japan*, 43, No. 6, 652-657 (1957) June.

The effects of silicon and carbon on the mechanical properties, corrosion resistance and shrinkage of acid-resistant high-silicon irons have already been reported by the authors. In the present investigation, the effects of various alloying elements, i.e., phosphorus, sulfur, vanadium, titanium, aluminum, arsenic, tin, manganese, nickel, chromium molybdenum, cobalt, copper and tungsten on these properties have been studied.

Results: (1) Elements showing favorable effects on the transverse strength of high-silicon iron were as follows: nickel (0.7%), cobalt (0.3%), chromium (0.6%), molybdenum (3%), tungsten (0.8%), vanadium (0.09-0.5%), titanium (0.3%), aluminum (0.06%) and copper (0.3-3%). (The numbers in parentheses indicate the optimum contents). (2) Elements promoting a growth of graphite, such as copper and aluminum, decreased the Rockwell hardness, while the elements, so-called carbide stabilizers, diminishing the size of graphite and facilitating formation of hard carbide-phases, such as manganese, phosphorus, chromium and molybdenum increased the hardness. (3) The corrosion resistance to sulfuric acid was improved by addition of manganese, phosphorus, nickel, cobalt, chromium, vanadium, copper and arsenic. Among these elements, copper was most effective. It was adversely affected by tin and sulfur. For hydrochloric acid molybdenum and nickel had good effects while tin and phosphorus had deleterious effects.—JSPS.
14261

6.2.2, 4.6.11, 8.9.5
The Corrosion Resistance of Ductile Iron in Sea Water and Petroleum Tanker Services. MICHEL PARIS AND B. DE LA BRUNIERE. *Corrosion*, 13, No. 5, 292t-296t (1957) May.

Laboratory data are given which compare the corrosion resistance of gray iron, steel and ductile iron in sea water and various acid solutions of different concentrations. Data also are presented to show the performance of ductile iron

INDEX TO ADVERTISERS

when used for product lines on petroleum tankers. Of particular interest is information presented for a low alloyed ductile iron which has given complete satisfaction under highly aggressive conditions in petroleum tanker service.
13846

6.2.3, 3.2.2, 1.6

Control of Steel Construction to Avoid Brittle Failure. M. E. SHANK, Editor. 1957, 184 pp. Welding Research Council, American Welding Society, 29 W. 39th Street, New York 18, New York.

Discusses importance of materials, design and fabrication in ultimate performance of steel.—INCO.
14136

6.2.3, 3.7.3

On the Corrosion of Ship Structural Steel: Effects of Pre-Strain and Welding. M. YOSHIKI, T. KANAZAWA AND Y. FUJITA. *J. Japan Society for Testing Materials,* 5, No. 38, 649-653 (1956) Nov.

In order to study the effects of prestrain and welding on the corrosion of ship structural rimmed steel, experiments were performed to determine degree of corrosion by measurement of electrical resistance increment of test pieces. The results obtained are as follows:

(1) Steel becomes more sensitive to corrosion as the amount of pre-strain increases.

(2) Particularly, corrosion of steel containing welded part is seriously accelerated.

(3) Effects of pre-strain on the corrosiveness of steel have been reduced by welding such as union welding which produces a large quantity of heat.—JSPS
13918

6.2.4, 2.3.7

Prot Fatigue Study of an Aircraft Steel in the Ultra High Strength Range. P. W. RAMSEY AND D. P. KEDZIE. Paper before Am. Inst. Mining Met. Engrs., Cleveland, October, 1956. *J. Metals* (Trans. AIME), 9, No. 4, 401-406 (1957) April.

Determination of relationship between fatigue and tensile properties of ASM-6434 (nickel-chromium-molybdenum-vanadium steel containing 1.72-1.83 nickel) in 155-280 ksi tensile strength range, using the Prot method of fatigue testing. Useful increase in fatigue strength of carefully ground specimens was found up to 240 ksi tensile strength with endurance ratio of 0.40-0.42; above this level fatigue strength appeared to level off or drop slightly. Every fatigue fracture initiated at non-metallic inclusion, pointing up importance of cleanliness of microstructure in fatigue applications. Some trend for failure stress to decrease as inclusion size increased was noted. Comparison with Wohler method showed worthwhile savings in specimens and test time through use of Prot progressively increasing load method.—INCO.
14043

6.2.5, 3.7.3, 5.9.3, 4.4.6

Quantitative Comparison of Surface Finishes and Heat Treatment of Stainless Steel with Respect to Corrosion by Jet Fuels. R. G. CARLSON. *Corrosion,* 13, No. 10, 672t-676t (1957) October.

Samples were made from free machining AISI 440C stainless steel. They were identically hardened and tempered at 16 different tempering temperatures. The samples were then given five different surface finishes (i.e., grit blast,

chro honed, ball burnished, ground and carburendum blast). After initial weighing the samples were subjected to a corrosion environment of JP-4 fuel and water. The samples were removed at varying times, cleaned and again weighed. Weight losses were compared for different tempering temperatures and different surface finishes.

From the test results it was concluded that: (1) This steel should not be heated above 400 C (750 F) for greatest corrosion resistance, (2) Corrosion is greater when no JP-4 fuel is above the water, (3) The order of corrosion resistance was due largely to surface roughness of the different finishes. This order, in decreasing corrosion resistance, is as follows: (a) Ground surface, (b) Ball burnished, (c) Carburendum blast, (d) Chro honed, (e) Grit blast.
14227

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.12

Further Studies of the Properties of Rhenium Metal (and the Platinum/Rhenium Thermocouple). CHESTER T. SIMS AND ROBERT I. JAFFEE. *Trans. Am. Inst. Mining Met. Engrs.* (J. Metals), 206, No. 8, 913-917 (1956).

[Cf. *ibid.*, 203, 168 (1955).] Further experimental work on the physical, mechanical and corrosion-resistance properties of pure rhenium is described. Young's modulus decreases with increasing temperature up to 900 C in an approximately linear manner, being 67.5 and 54 x 10^6 lb./in.^{2} at room temperature and 880 C, respectively. The 100-hr. rupture stress is 20,000 lb./in.^{2} at 1000 C and 800 lb./in.^{2} at 2000 C, estimated from a Larsen-Miller plot. Annealed sheet has a 0.1% offset PS of 131,000 lb./in.^{2} and a UTS of 168,000 lb./in.^{2} and an elongation of 28%; sheet reduced 30% by cold working has a 0.1% offset PS of 282,000 lb./in.^{2} a UTS of 322,000 lb./in.^{2} and an elongation of 2%. Cold swaging or wave drawing work hardens the metal more than does rolling. Additions of thorium dioxide reduce the UTS and ductility, and lower the recrystallization temperature. Molten silver, copper, tin and zinc do not attack the metal, but it is slowly attacked by molten aluminum and readily dissolves in molten iron and nickel. The thermo-emf of the platinum-rhenium thermocouple at temperatures up to 1600 C follows the relationship E = 1.56 — 0.90 x 10^{-2}T + 1.29 x 10^{-5}T,^{2} where E is the emf in mV. and T is in °K. The first derivation gives the thermo-electric power P = —9.0 + 2.58 x 10^{-2}T μV/°K.; P increases linearly with increasing temperatures so that the couple has increasing sensitivity with increasing temperature and rhenium should, therefore, be most useful at the highest temperatures. 8 references.—MA.
13738

6.3.13, 8.10.2

Tantalum: Its Manufacture and Chemical Uses. G. L. MILLER. Brit. Chem. Eng., 1, No. 3, 152-157 (1956) July.

Treatment of the ores by alkali fusion or solution in hydrofluoric acid, production of the metal by sodium reduction or electrolysis of fused K_2TaF_7, methods of handling hydrofluoric acid and sodium, consolidation of tantalum powder, future prospects (including possible production by magnesium reduction of tantalum chloride), corrosion resistance and properties of the metal.—BNF.
14092

DURIRON

## *provides low cost, long term protection*

THE PROBLEM: To protect the steel rake arms and influent wells in three 200′ diameter presediment basins.

THE ANSWER: Duriron impressed current anodes! Strings of Duriron 1¼″ dia. x 9″ long anodes were 1) extended along both sides of the rake arms, 2) hung vertically to protect the lower section influent wells and center structures, and 3) suspended horizontally on a 16½′ radius at a depth four feet below the water level.

These systems have been in operation for 18 months (220,000 ampere hours per basin). The structures are thoroughly protected, and the consumption rate of the anodes is approximately 0.25 lbs./amp. yr. The life expectancy of the systems is 15-20 years.

THE DURIRON COMPANY, INC., Dayton, Ohio

DURIRON® IMPRESSED CURRENT ANODES
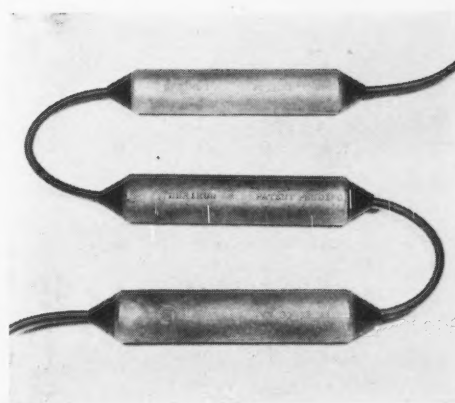
Duriron anodes are available in a variety of shapes and sizes for applications in fresh water, ground bed, and salt water services. For complete details, see your cathodic protection specialist or write The Duriron Company, Inc.; Dept. CP; P. O. Box 1019; Dayton, Ohio.
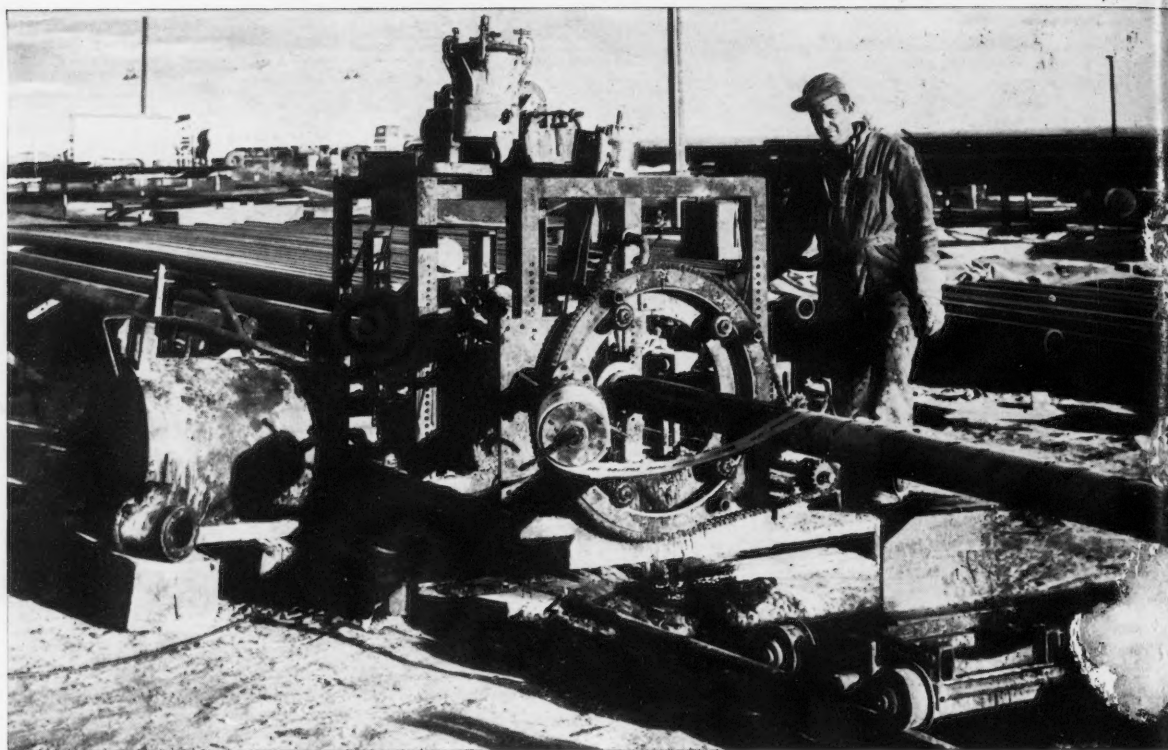
TARSET® Protects High Temperature Gas Injection Lines from Corrosion in Elk City Field

GAS injection lines serving the Hoxbar Unit in the Elk City, Oklahoma oil and gas field face some very tough underground corrosion conditions.

Operated by the Shell Oil Company for Shell and 31 other participating members, the Elk City Processing and Gas Cycling Plant recycles gas through the injection lines to 15 injection wells, maintaining reservoir pressure and increasing the field's ultimate recovery.

Because the carbon steel injection lines carry gases up to 230°F. and pass through spots where trapped water creates very corrosive conditions, the lines soon began to corrode despite heavy wall thicknesses.

Shell recently reconditioned the injection line system—some six miles of pipe—and coated the lines with Pitt Chem *Tarset*. A patented coal tar-epoxy resin coating, *Tarset* was selected because of its excellent service record in the petroleum industry and its ability to withstand high temperatures and corrosion conditions. *Tarset* was applied by spraying. Future coating may be done by the experimental machine illustrated above.

What's *your* toughest corrosion control problem? Perhaps tough, durable, cold-applied Pitt Chem *Tarset* can solve it for you. *Tarset* is available through your local Industrial Distributor. *Call him for more information today!*

Think First of the Coatings that Last!

★ **PITT CHEM**
Coal Tar Coatings

★ **PITT CHEM**
"Insul-Mastic" Gilsonite Coatings

★ **PITT CHEM**
"Tarset" Coal Tar-Epoxy Resin Coating

PITT CHEM Industrial Coatings are available through leading Industrial Distributors. See the "Yellow Pages."

PROTECTIVE COATINGS DIVISION
PITTSBURGH
COKE & CHEMICAL CO.
Grant Building • Pittsburgh 19, Pa.

WSW 7139

PROTECTIVE COATINGS • PLASTICIZERS • COAL CHEMICALS • ACTIVATED CARBON • COKE • CEMENT • PIG IRON